

**NASA GRANT/COOPERATIVE AGREEMENT NO. NAG4-134**

**DEVELOPMENT OF A TEACHING TOOL TO ENCOURAGE HIGH SCHOOL  
STUDENTS TO STUDY AEROSPACE TECHNICAL SUBJECTS**

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# NASA Aerospaceport Design Competition



Welcome to the First NASA Aerospaceport Design Competition! This event is an industry simulation game for high school students. Teams of students prepare designs for airports of the future, which are major hubs for both aircraft and spacecraft carrying cargo and passengers for commercial operations. The Competition is designed so that success requires members of the teams to understand and apply a vast array of knowledge and provide creativity, drawing, writing, and communication skills. They will:

- consider how future air and space vehicles will operate
- depict functional buildings to service vehicle and user needs
- design the ground transportation infrastructure involved with a major port
- include features that will be pleasant and helpful to passengers, cargo shippers, and employees develop concepts for computer and robot systems to operate the aerospaceport
- estimate costs and schedules for developing the aerospaceport
- prepare a written documents describing the design

The competition is modeled after and parallels the International Space Settlement Design Competition. Both competitions are exercises of creativity, technical competence, aesthetics, management skills, teamwork, and presentation techniques. Aerospaceport Competitions offer the same magnitude of challenge as the Space Settlement Design Competitions, but provide an option for practicing the same industry skills without the complication of learning about and designing for the space environment.

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## About the Competition

These materials (see the other pages, too!) will get you started in the Competition. Your team must **register** with the Competition organizers to receive key Competition materials not included here. The 1997-1998 National Aerospaceport Design Competition is conducted in two phases:

**Phase 1: Qualifying Competition** (at your high school) Your team represents a major aerospace or construction company. The Preliminary Request for Proposal (RFP) summarizes the requirements for the Aerospaceport desired by the customer. When your team registers for the Competition, you will receive the Final RFP, with details of what your design must include. Create and submit your design for the Aerospaceport, in hopes that your company will be awarded the lucrative contract to construct it. Submit your written (on paper!) design description by April 2, to judges who will evaluate the proposals and select eight Finalist teams to attend the Finalist Design Competition at NASA - Dryden Flight Research Center in California, June 20-22, 1998.

**Phase 2: National Finalist Competition at NASA - Dryden in California** The eight Finalist teams will be paired to form four competing companies. Your company will prepare designs at NASA - Dryden, June 20-21, for a different Aerospaceport scenario. You will work in conditions that resemble those experienced by members of high-pressure proposal teams in industry, with assistance from real working engineers and managers. Designs will be presented June 22 to an audience that includes the judges and competing companies.

Presenters will answer the judges' questions about their designs. Judges will select a winning design, and provide a debriefing describing merits and weak points of the proposals. Aerospaceport Design Competitions will be conducted in future years with different scenarios and sets of design requirements each year. Subtleties of site selection and changes in vehicle requirements will make each Competition a new challenge for the participating teams.

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## Competition Paradigm

The 1997-1998 Aerospaceport Design Competition will take place in a simulated future: the year 2040. Technological advancements beyond the current state of the art have accrued.

For the Qualifying Competition, your company is Flechtel Constructors, and the customer is an organization called the Foundation Society. The contents of these links describe technologies the judges will accept in your design. Any other advanced technologies assumed in your design must be fully justified (for example, if you plan to teleport cargo to the Aerospaceport site, you must explain how the teleportation system is constructed).

The basic products, vehicles, and structures described for this Competition are technically possible within the timeframes indicated. They do, however, represent ambitious technical, economic, and political commitments. Some will never happen, some will. Some are projects that Design Competition participants who become engineers will work on during their careers.

The company Flechtel Constructors, including its product line and history, is based on a composite of real corporations, projected

into the future. There is no such organization as the Foundation Society. The described efforts by the Foundation Society to foster commercial space infrastructure development could, however, be accomplished by other existing organizations.

Your proposal will be judged by engineers working in NASA and the aerospace industry, so please base it on reasonable interpretations of the level of existing technology defined here, the laws of Physics, and common sense.

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## Details

Qualifying Competition teams may be of any size (e.g., 25 or 30 students). The eight teams that qualify for the Finalist Competition will be limited to 12 members (who must be High School students during the 1997-1998 school year) each -- and two adult advisors. Your team will be most likely to succeed if it includes members with diverse experiences and/or interests, and if your design balances structural integrity, operating efficiency, use of computers and robotics, and pleasant living conditions. Related Competitions have shown that it will also be helpful to have at least one good artist and/or one good writer on your team. Competition sponsors will provide lodging and meals during the Finalist Competition for each team's 12 students and two advisors. The presentations in the Finalist Competition will be in a briefing chart format, and be limited to 35 minutes plus 10 minutes for questions from the judges.

The Competition experience is offered at no charge to participating student teams. Donations by sponsors enable the Competition organizers to provide complimentary lodging and meals for Finalist Competition participants. Finalist teams will, however, be expected to fund their own transportation to the Competition site (Lancaster, California, in even-numbered years; Hampton, Virginia, in odd-numbered years).

The Competition organizers occasionally develop new background materials that might be helpful as your team develops its design. Check here periodically to access this information as it is added. A Change Log will identify additions and the dates when they were added.

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## Flechtel Constructors

Flechtel Constructors has been in business since the 1920's, when it designed and built facilities for energy and chemical companies. Until the late 1960's, Flechtel products were primarily oil refineries and factories producing industrial chemicals, fertilizer, and household cleaning products. The company has skills, however, for designing nearly any industrial, commercial, or government facility, and has been involved with power plants, ground transportation infrastructure, farming, logging, amusement parks, harbors, and airports. In the 1970's, the company was known for its designs of entire cities in the Saudi Arabian desert, including airports and water desalination plants.

Flechtel expanded rapidly during the 1990's with contracts to upgrade Russian and Kazakhi oil industry and petrochemical plants, modernize the ground transportation infrastructure of Russia, Ukraine, and (European) Georgia, clean up environmental damage in Eastern Europe and Northern Asia, and rejuvenate several Eastern European cities. In the 2010's, Flechtel designed and built the Kenyan veldt and Pacific Ocean launch sites, and has since assisted with upgrades to these facilities to accommodate new launch vehicle designs. A large percentage of its business in the 2020's resulted from its leadership in developing designs for modifying airport facilities to service aircraft with cryogenic fuels. A consistent company philosophy is that every customer is important, and no project is too big, too small, or too strange.

Low-cost and high-quality construction techniques, developed during the post-Soviet construction boom, were applied after the year 2000 to bring about rapid industrialization in developing countries. The company began assisting poor nations in generating capital for major building projects by entering into joint ventures with them. This was done to develop capital-earning industrial bases through construction and operation of factories while using each nation's workforce skills and natural resources. Flechtel employees assure success of these ventures; they stay with the plants through start-up, conduct training programs for local workers, and periodically return to see that no problems are developing and to introduce improvements in plant operation. This program has so greatly benefited developing nations that Flechtel was awarded a Nobel Peace Prize in 2011.

The company again gained humanitarian recognition in the 2020's, when it developed a design and demonstrated feasibility of operating huge ocean farming systems. Other companies have since developed their own designs for these facilities, and now dozens of them are operating in remote deep-water areas of the Pacific and Indian Oceans, far from land and pollution. Isolation from contaminants enables farm operators to better control nutrients provided to fish and aquatic vegetables, and to better control diseases. The development of these farms has assured virtually inexhaustible food supplies for Earth's peoples. Flechtel has been associated with the aerospace industry since the late 1980's, when it assisted a launch vehicle manufacturer with research into requirements for construction of human habitats on the lunar surface. Flechtel has since been involved in some way with every major construction project involving industrialization of space. The company designed interiors for habitation modules of the first International Space Station, supervised Space Station expansion into a Low Earth Orbit space port, and was a major subcontractor for the other two LEO space ports that now serve as transfer points for all passengers and cargo moved between Earth and other space destinations. The company developed living area interiors for U.S. lunar bases, life support systems for hotels and resorts in orbit, and port and tourist facilities adjoining Foundation Society settlements in orbit and on the moon. Flechtel has assisted developers of space manufacturing facilities, by designing large-scale processes to create commercially useful quantities of products made experimentally in Space Station laboratories. It has provided habitats for workers in asteroid and lunar mining ventures. The company designs microwave transmission equipment for Solar Power Satellites, and is the world's largest producer of receiving antennas for space-generated power.

Flechtel managers believe that the company is uniquely qualified to win the Foundation Society's Ameriport contract, given its extensive and diverse experience with major dirtside and on-orbit projects, including airports, spaceports, cities, and a variety of infrastructure projects.

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# NASA Aerospace Design Competition



## The Customer

The Foundation Society is an organization founded for the specific purpose of establishing settlements of its members in space. Aside from modest offices and training facilities for members before they leave to live in space, the organization has had no property on the surface of planet Earth. The Society has finally realized, however, that its operations in space are being adversely affected by the inadequacy of existing ground infrastructure to support the transportation needs of the space settlements and their associated businesses.

With more settlements in the planning stages, the Foundation Society has determined that it must make the investment itself. It is offering companies the opportunity to bid on a contract to build Earth's first full-service Aerospaceport, which will enable efficient and comfortable transfer of passengers and cargo from Earth to space.

The Foundation Society first began influencing space policy in the mid-1990's, when it led several grass-roots space advocacy organizations in fostering development of commercial Earth orbit infrastructure -- particularly by researching profit potential for launch vehicles providing lower costs per pound to orbit. The Society assured that these new launch vehicles would have customers, by providing venture capital for companies developing new products that utilized or required launch services. Foundation Society lobbying in Congress resulted in favorable tax and equity-protection laws for companies investing in perceived high-risk ventures with long-range return, commitments for government-sponsored scientific and exploratory space missions that further assured a strong customer base for commercial launch services, and removed the government from the businesses of launch vehicle operation and space hardware fabrication. The results of these efforts encouraged American corporate interest in commercial development of the launch vehicles and space infrastructure that make large-scale access to space practical.

The Society began operation of its first settlement for 10,000 of its members in Earth orbit late in 2012. Since that time, two more settlements have been established in Earth orbit, one settlement is operating on the lunar surface, and the second lunar settlement and first settlement in orbit around Mars are under construction. Plans are in various stages of development for more large space settlements; this expansion of infrastructure will continue as long as promising new sites are available, and economic reality permits. There are currently over 70,000 Foundation Society members living in space, with expectations to increase its space-based population by an average of 3000 people annually for the foreseeable future. The space settlements also have facilities to host 6000 visitors, who stay for an average of three weeks each.

Although the Foundation Society has developed sufficient financial reserves to invest in expensive projects like Space Settlements, the organization's goal is to build as many as possible, and therefore to develop an efficient construction infrastructure. To this end, lunar materials have been utilized extensively in the existing settlement designs. The space settlements have established vigorous and automated manufacturing and agricultural capabilities that provide necessities in orbit. There are, however, some small consumer goods, designer clothing, and luxury brand-name edibles that are shipped to residents of settlements in space. Launch costs cause these items to be very expensive, so as frequently as possible they are loaded as "bonus cargo" on passenger ships that have not been loaded to their allowable liftoff weight.

The Foundation Society intends that each community eventually be self-supporting through trade and services it can offer to Earth and other bases and settlements. Launch vehicle operators make most of their profit from flying passengers and cargo into space, so return trips for goods manufactured in the Foundation Society's space settlements enjoy relatively low transportation costs. Indeed, some inexpensive trinkets are worth shipping to Earth just because the dirtside population has a fascination with owning something that was made with extraterrestrial materials. Goods manufactured in Foundation Society facilities are primarily intended for use in space, but depletion of high-yield mineral resources on Earth and development of efficient mining techniques and refining processes for lunar and asteroid resources are causing the Foundation Society to seriously consider sending titanium and other valuable bulk materials to Earth.

The Foundation Society is unwilling, however, to initiate large-scale shipping operations within the existing infrastructure for launching and landing space vehicles. Launch sites have been operated with basically the same philosophy for 80 years: they are in remote locations, they do not share facilities with any other businesses or vehicles, their processes for handling cargo are complex and time-consuming, and their treatment of passengers is inconvenient at best.

The Foundation Society envisions a launch site, an Aerospaceport, which it will both own and operate, and which will resemble an airport with flight schedules that serve both terrestrial and orbital destinations. Although the primary initial motivation for this facility is to improve passenger service for its own members and visitors, and to provide efficient cargo operations to support its own settlements and business interests, it is anticipated that operators of on-orbit resorts and manufacturing operations will also be interested in operating flights through the Foundation Society Aerospaceport.



## Request for Proposal

1 January 2040

### "Ameriport" Contract

**Introduction** This is a request by the Foundation Society for selected contractors to propose the design, development, construction, and operations planning of "Ameriport", a USA-based Aerospaceport to accommodate spacecraft launches and landings, and commercial and private aircraft.

**Format and Schedule** Proposals shall be no more than 40 single-sided pages long, and are to be mailed on paper to the Foundation Society, for arrival by April 2 (electronic submittals will not be accepted). Readability and legibility count!

**Statement of Work** Your proposal should include all of these items:

1. **Basic Requirements** - The contractor shall describe the design, development, and construction of Ameriport, within the requirements specified in this Statement of Work. The contractor shall further develop the approach to operate and support the community.
2. **Facilities** - The customer requires that when Ameriport begins operations, it will provide the ability to accommodate launches and landings for up to two passenger spacecraft and two cargo spacecraft per day, runways and six gates for commercial passenger aircraft, and facilities for private aircraft and business jets. The design shall enable Ameriport expansion to its anticipated status as a primary hub for one major domestic airline, with facilities to accommodate a spacecraft launch and a spacecraft landing every hour. When Ameriport begins operations, it must provide servicing, fueling, and maintenance facilities for all arriving spacecraft. Routine fueling and servicing facilities must be provided for aircraft; after expansion, full maintenance facilities must be provided for one major domestic airline.
3. **Operations** - The proposal shall recommend a location in the United States for Ameriport, and cite reasons for its selection. The proposed Ameriport design shall include elements of basic infrastructure to support the needs of passengers and employees, including delivery of food, electrical power, water, and communication services. Provisions shall be described for efficient management of waste water, sewage, and solid waste. Ground transportation infrastructure must be provided to enable efficient cargo shipping, and arrivals and departures of passengers by private vehicles, and public transportation including busses and trains.
4. **Human factors** - Ameriport shall provide facilities expected by travellers through major hub airports, including a hotel, shops, connectivity for business communication, and activities to occupy hours between flights. The proposal shall define the number of employees required to conduct all the activities (functions) which must be fulfilled to operate the facility, and the number of employees required to perform each function. The proposal shall describe either expansion of housing and services in an existing nearby community, or development of a new community for Ameriport employees and their families.
5. **Automation** - The necessary automation support for Ameriport facility operations (e.g., arrival and departure communication, data systems, luggage transport, etc.) shall be specified, including identification of number and types of computers, software, network planning, and robotic applications. Automation systems shall also be described for living quarters and community services that will be built to accommodate Ameriport employees and their families.
6. **Schedule and Cost** - The proposal shall include a schedule for completion, occupation, and operation of Ameriport, and costs for design through construction.

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# NASA Aerospaceport Design Competition



## Aerospaceport Design Competition Sponsors

Aerospaceport Design Competitions are jointly sponsored by NASA - Dryden Flight Research Center and NASA - Langley Flight Research Center, with support by industry partners.

The Co-Founders and Organizers of the National Aerospaceport Design Competition are Anita Gale and Dick Edwards, engineering managers with the Space Shuttle program for Boeing North American's Space Systems Division in Downey, California. Anita and Dick are also Co-Founders of several Space Settlement Design Competitions, with a legacy of providing industry experiences to young people since 1984. Competition materials and organization are provided by Ms. Gale and Mr. Edwards under the auspices of the American Institute of Aeronautics and Astronautics (AIAA).

Volunteers who provide technical and managerial assistance to teams competing in the Finalist Competition are employees or retirees of NASA, other government agencies, and industry partners. Additional volunteer support is provided by members of AIAA and the National Council for Women in Aviation/Aerospace

If you have questions or comments about the Competition or these materials, you are welcome to contact the Competition Organizers:  
Anita Gale < [anita.e.gale@boeing.com](mailto:anita.e.gale@boeing.com) >  
Dick Edwards < [dick.edwards@boeing.com](mailto:dick.edwards@boeing.com) >

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# Aerospaceport Design Competition GLOSSARY

Many of the words and terms used in Aerospaceport Design Competition materials are not part of familiar everyday usage:

**aerospaceport:** facility that provides runways for aircraft, launch and landing sites for space launch vehicles, maintenance and services for both, and accommodations for passengers and cargo for both

**air-breathing engine:** propulsion plant (motor) that acquires oxidizer from the air, rather than carrying it in tanks on the vehicle (as required by rocket engines)

**aircraft:** vehicle(s) designed to fly in Earth's atmosphere

**airport:** facility that provides runways, maintenance and services, and accommodations for passengers and cargo that fly on aircraft

**avionics:** literally, "aviation electronics", mostly including commanding and monitoring of systems on aircraft and spacecraft

**cargo:** the reason a vehicle flies; stuff that is carried by a vehicle from its starting point (ground or on-orbit) to the vehicle's destination; can include satellites, bulk materials, construction components, or people

**cargo container:** standard carrier in which cargo is carried for a mission; ideally, all spacecraft cargo is containerized, because complex installations and interfaces can be accomplished to the inside of the container, and the standardized exterior interfaces of the container can be quickly mated to the inside of a cargo vehicle (standardized containers have been used for decades on ships, conventional aircraft, railroad cars, and trucks)

**checkout:** testing process to verify that vehicles, equipment, and/or computers are functioning as they were designed to function, and that they are ready for the mission they are intended to perform

**community:** a group of humans of any size whose members reside in a specific locality, and share infrastructure, retail services, and government

**consumables:** stuff that is used up during the course of a mission or over a period of time, and hence must be replaced; includes everything from rocket fuel to pet food to pencils

**contract:** a legal agreement between a customer and a company (contractor), whereby the contractor agrees to build something or provide a service within a defined cost and schedule, and the customer agrees to pay the cost when the product is delivered (contracts may have provisions for partial payments over the course of a long product delivery schedule)

**dimensions:** measurements of size; on design drawings, numbers shown adjacent to drawings, to indicate sizes of the items shown in the drawings

**dirtside:** of or referring to Earth, people living there, and things on it

**Expendable Launch Vehicle (ELV):** a launch vehicle which is used for only one launch; typically, it sheds some of its components, or stages, during the launch process, with only a small portion of the original "stack" being delivered all the way to orbit

**fabrication:** manufacture; the process of making, building, and/or assembling

**facility:** building or other structure, or collection of buildings/structures, designed to provide a function or service

**fiber optics:** use of tiny, transparent strands to transmit light that represents electronic signals; can replace traditional copper wire with less weight and expense, and greater reliability, but is not capable of transmitting power

**fueling:** process of loading propellant(s) into the tanks of a vehicle

**GEO:** geosynchronous Earth orbit; objects in 22,300 mile orbits rotate around the Earth at the same rate that the Earth turns on its axis; when located above the Equator, these objects appear to be stationary in Earth's sky

**ground operations:** tasks performed on the ground, preparatory to flight, to prepare an aircraft or launch vehicle for flight; can include fueling, checkout, maintenance, or any other tasks that can only be performed when the vehicle is on the ground

**hypersonic flight:** flight through an atmosphere at greater than five times the speed of sound (Mach 5) for that atmosphere

**infrastructure:** the collection of electrical power and other utilities, water, sewage, solid waste disposal, food and goods delivery, communications, transportation, and other services required to support a community

**Lagrangian points:** (see "libration points")

**landing:** process by which an aircraft or launch vehicle returns to and comes to a controlled stop on the ground--horizontal landings occur on a runway, with the vehicle touching down on wheels; vertical landings occur on a flat surface (e.g., for helicopters or some launch vehicles) or pond of water (e.g., for heavy lift launch vehicles)

**launch:** process by which a vertical take-off launch vehicle ascends from the ground to get into space and achieve orbit; requires a launch pad

**launch pad:** facility on the ground from which a vertical take-off launch vehicle ascends; requires capability to withstand the heat of rocket exhaust, requires either the capability to move the launch vehicle from a cargo-loading facility or to load cargo into the vehicle at the launch pad, and requires capability for fueling the vehicle

**launch site:** facility at which launch vehicles are prepared for their missions, and from which they ascend (either horizontally or vertically) to get into space and achieve orbit

**launch vehicle:** a spacecraft that is capable of launching or flying through an atmosphere (e.g., Earth's) in order to get into space and achieve orbit

**LEO:** low Earth orbit; orbital locations above Earth's atmosphere and below the Van Allen radiation belts

**libration points:** in orbital mechanics, when one large body (e.g., the Moon) is in orbit around another large body (e.g., Earth), there are five points in orbits around the larger body where gravitational forces balance out to enable satellites to be placed where they could not stay if the smaller of the large bodies were not present (also called Lagrangian points, for Joseph Lagrange, the mathematician who developed the theory that predicts their existence)

**low-g:** acceleration environment with less than the acceleration due to gravity on Earth's surface

**maintenance:** services provided to a vehicle, structure, or equipment, in order to assure that the item being maintained remains in working order and is capable of accomplishing its functions; can include repairing, replacing components, painting, cleaning, lubricating, and topping off fluid levels in brakes/hydraulic and other systems

**mass driver:** a device that electromagnetically accelerates small objects to very high velocities; can be utilized for efficiently launching material from airless surfaces

**micro-g:** an accurate description of "weightlessness", the condition experienced in space when forces balance out and objects seem to "float"; true "zero-g" is theoretically not possible, because there are always some tiny forces operating on all objects

**modal testing (non-destructive):** process by which a vehicle is placed in a facility where it is subjected to vibrations; the vehicle's motions in response to the vibrations are measured and compared with the vehicle's original response to identical vibrations--a means for determining that the vehicle's structure is intact and undamaged

**on-orbit:** in space, in an orbit; usually refers to an orbit around Earth

**operations:** processes by which facilities, vehicles, communities, and other entities or things accomplish their objectives

**orbit:** the path assumed by an object in space, due to balancing or "cancelling out" of accelerations due to gravity and rotation; usually the elliptical path of a small body (e.g., satellite) around a very large body (e.g., planet, moon, or star)

**overhaul:** extensive maintenance process; restoration of a vehicle with deteriorated performance to like-new condition, and/or modification to improve performance

**overhead:** the part of a budget that does not show up as part of the cost of work directly on a project, but is charged to the customer as part of the hourly charge for direct work (i.e., a contractor is paid for each hour an engineer works on tasks directly related to the project; the customer is billed a cost for the engineer's hours that is greater than the salary paid to the engineer; the difference pays for computers, upkeep of the facility, janitors, utilities, secretaries, and other costs required to support the engineer's work)

**payload:** literally, "paying load"; cargo carried by a vehicle, for which a fee is being paid in exchange for moving the cargo to its destination

**payload capability:** weight of payload(s) that a launch vehicle is capable of carrying to orbit

**payload integration:** the process of safely stowing a payload (usually a satellite or complex device) on a launch vehicle and providing services (often including electrical power, avionics, and thermal control) that enable the payload to survive the flight and accomplish its purpose; includes design of payload services, analysis of payload's ability to survive environments it will experience, and installation in the vehicle

**profit:** the difference between the price charged by a contractor for providing a product, and the actual cost the contractor incurs to make the product

**propellant(s):** for an aircraft, fuel; for a launch vehicle or other spacecraft, liquid or slush fuel and oxidizer for rockets or air-breathing engines, or solid fuel for some rockets

**proposal:** a document prepared by a company or other entity, in order to convince a customer to select the company as the contractor that will provide a certain product; it describes the company's recommendation for how it could provide the product, and explains why the customer should have confidence that the company has a superior design and can be relied upon to produce it according to the customer's requirements and within the described cost and schedule

**Request for Proposal (RFP):** a document prepared by a customer, which describes features of a product they want a contractor to produce

**requirements:** features that a customer requests to be included in the design of a desired product

**Reusable Launch Vehicle (RLV):** a launch vehicle that returns from its missions intact, and is designed to be maintained after flight and fly repeated missions

**RFP:** see "Request for Proposal"

**satellite:** any object in orbit around another object; usually refers to human-made devices in orbit around large natural bodies (i.e., planets, moons, stars)

**servicing:** processes by which engines and vehicles are fueled, moved, loaded, maintained, and otherwise prepared for their next flight

**Single Stage to Orbit (SSTO):** the capability of a launch vehicle to accomplish a mission from the ground to orbit without staging, or shedding of components during the launch process; such vehicles contain all of the fuels and oxidizer they require in tanks inside their structures, and return to the ground with the tanks intact (the amount of oxidizer required can be reduced through use of air-breathing engines during flight in the atmosphere)

**slush hydrogen:** liquid hydrogen fuel that has been super-cooled to achieve a near-solid state, so that it is denser and enables more hydrogen to be carried in a tank

**solar panel:** a device that converts sunlight into electrical power

**Solar Power Satellite:** a satellite, usually very large, consisting mostly of large arrays of solar panels producing electrical power that can be converted (usually to microwave energy) and transmitted to users in other locations

**solar sail:** a surface, usually very large and lightweight, that makes use of pressure due to light or solar wind for propulsion

**SOW:** see "Statement of Work"

**space settlement:** facility in space constructed to provide protection from the space environment, and in which humans establish communities

**spacecraft:** vehicle(s) designed to fly in space, including launch vehicles that fly between Earth's surface and orbit

**spacer:** of or referring to people who live in space

**spacesuit:** garment that provides pressure, breathing air, fluids and nutrients, waste removal, and protection against the space environment, and that enables a human to move and operate in the space environment

**spaceport:** facility that provides launch and landing sites, maintenance and services, and accommodations for passengers and cargo that fly on space launch vehicles

**SSTO:** see "Single Stage to Orbit"

**Statement of Work (SOW):** the section of an RFP that describes the tasks a contractor is expected to perform, and/or the requirements for the design that the contractor is expected to create and build

**support (of a facility):** infrastructure and services required to enable a facility to operate in the way that it was intended

**take-off:** process that an aircraft or launch vehicle employs to leave the ground and rise into the air, in order to achieve its mission--airplanes and some launch vehicles take off horizontally from a runway; helicopters and some launch vehicles (especially heavy-lift launch vehicles) take off vertically

**Van Allen radiation belts:** bands of radiation trapped in Earth's magnetic field, which both absorb ambient deep-space radiation

and provide protection for Earth's surface, and are a hazard for satellites and humans operating within them

**zero-g:** see "micro-g"

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Last Modified: January 1, 1998  
Responsible NASA Official: Lee Duke  
Web Page Curator: Dennis daCruz

# NASA Aerospaceport Design Competition



## National Aerospaceport Design Competition Team Registration Form

Online registration will be available until February 10, 1998. If your team registers after February 10, your registration must be mailed along with a \$15.00 check made out to "AIAA Orange County Section", to cover the cost of sending registration materials by Express Mail. A PDF version of the [online form](#) is also available. Instructions for mailing are on the form.

**Teacher/Advisor Name:**

Teacher Name

**School Name:**

Name of Your School

**School Address:**

School Address

**School City, State, Zip:**

City, State, Zip

**Email address:**

Email address

**Day Telephone:**

phone

**FAX Number:**

Fax Number

Submit

Reset

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Last Modified: December 8, 1997  
Responsible NASA Official: Lee Duke  
Web Page Curator: Dennis daCruz

# National Aerospaceport Design Competition Team Registration Form

Print this form, fill in the information on the paper copy, and mail it to:

Marianne McCarthy  
NASA - Dryden Flight Research Center  
M/S 4839A, PO Box 273  
Edwards, CA 93523

There is no fee for the Competition for registrations received by February 10, 1998. **If your team registers after February 10, enclose a \$15.00 check** made out to "AIAA Orange County Section", to cover the cost of sending registration materials by Express Mail.

The following information – paper copy with an original signature – must be received at Dryden Flight Research Center before registration materials, including the Final RFP, will be sent to competing teams:

Teacher/Advisor Name \_\_\_\_\_  
School Name \_\_\_\_\_  
School Address \_\_\_\_\_  
School City, State, Zip \_\_\_\_\_  
Email Address \_\_\_\_\_  
Day Telephone \_\_\_\_\_  
FAX Telephone \_\_\_\_\_

*I understand that if our Team qualifies for the National Aerospaceport Design Finalist Competition at NASA - Dryden Flight Research Center during June 20 - 22, 1998, we will be required to find our own travel to and from Lancaster, California.*

\_\_\_\_\_  
Signature of Teacher/Advisor

\_\_\_\_\_  
Date



# ANTELOPE VALLEY

## OF HOPE UNIVERSITY

## DESIGN COMPETITION



OCTOBER 10-12, 1997





# Space Settlement Design Competition

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## Acknowledgements

The Space Settlement Design Competition was made possible by donations of funding, materials, services, and time by several organizations, companies, and individuals. The following have earned special recognition for their generosity:

### COMPETITION ORGANIZERS

**Dick Edwards**

Boeing North American; Downey, California

**Anita Gale**

Boeing North American; Downey, California

### SPONSORS

**NASA - Dryden Flight Research Center**

With special thanks to Lee Duke and Marianne McCarthy

**Antelope Valley Union High School District**

With special thanks to Superintendent Dr. Bob Girolamo

**Antelope Valley High School**

With special thanks to Michael Dutton and Moses Primus

**American Institute of Aeronautics and Astronautics Orange County Section**

### DONORS

**Lancaster West Rotary Club**

With Special Thanks to Howard Harris

### SUPPORTERS

**Boeing North American**

With special thanks to Tom Kennedy and Bob Tucker

**American Institute of Aeronautics and Astronautics Antelope Valley Section**

With special thanks to Alan Sutton



# Space Settlement Design Competition

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## Acknowledgements

It would not be possible to conduct the Space Settlement Design Competition without the selfless contributions of volunteers. The Competition organizers and sponsors sincerely appreciate the efforts of the following individuals:

### CHIEF EXECUTIVE OFFICERS

Michelle Davis  
NASA - Dryden Flight Research Center

Dale Reed  
NASA - Dryden Flight Research Center

Lee Pitts  
Consultant

Max Vallejo  
Boeing North American

### STRUCTURAL ENGINEERING TECHNICAL EXPERTS

Alan Sutton  
AIAA Antelope Valley Section

Ed Teets  
NASA - Dryden Flight Research Center

### OPERATIONS ENGINEERING TECHNICAL EXPERTS

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General Atomics

J Shelley  
AIAA Antelope Valley Section

Lauren Pomerantz  
California Space and Science Center

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AIAA Antelope Valley Section

Capt. Michael Lindauer  
Edwards Air Force Base

Karen Kuhn  
Consultant

### AUTOMATION ENGINEERING TECHNICAL EXPERTS

Michael Frye  
AIAA Antelope Valley Section

Tom Quayle  
Consultant

Jeff Kuhn  
Edwards Air Force Base

### ADMINISTRATIVE SUPPORT

Tom Quayle

## **Foundation Society to Build Settlement on Mars**

Foundation Society President Edwards Smith announced today that the organization's next space settlement--its seventh community in space--will be on Mars. Although it was confirmed that the settlement, tentatively designated "Argonom", will be on the Martian surface, a location was not specified. The Foundation Society seeks contractor advice for selecting settlement locations. This will be one of the Society's smaller settlements, with a population of only 12,500, but it is expected to be the first of many communities on Mars. The Foundation Society's decision was based on results of a planetary survey conducted by two dozen of its members over the past three (Earth) years. Mission leader Gale Uttamchandani and three team members returned recently to Foundation Society headquarters at Columbiat to report on their findings.

Uttamchandani said that the team typically travelled 50 km (30 miles) per day, and visited every major geological (areological, on Mars) formation on the planet. The team used three rovers with high ground clearance and eight wheels on independent axles. According to Engineer Tom Yubickovich, "the rovers worked really well. Sometimes one got stuck in some loose stuff or in rocks, but we could always use the others to pull it out of trouble." The rovers provided living quarters much like a recreational vehicle. Supplies were dropped by parachute every 90 days.

Members of the survey team are enthusiastic in their praise for Martian scenery. Areologist Peter Lee said "sometimes we came to the edge of an escarpment or rounded a corner in a valley, and we just had to stop to take it all in. Pictures don't do it justice. It was incredible: grand vistas, sweeping panoramas, stark and almost surreal."

The survey showed that resources on Mars are as widely distributed as on Earth, and the resources a community needs are not all in one place. Water is mostly in the north, in the polar cap and underground in higher latitudes. Surface material composition is almost uniform around

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-- more -- more -- more --

## Next Foundation Society Settlement on Mars

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the planet, owing to millenia of dust storms. The dirt has a variety of useful minerals in it, but not in commercially useful concentrations. Rocks are mostly unremarkable crater ejecta. Useful ore deposits are mostly in the southern highlands (exposed in deep crater walls), on the flanks of the Tharsis and Elysium volcanic regions, and exposed in canyons like Valles Marineris.

The team was perplexed in its search for evidence of life on Mars. As Uttamchandani said, "Mars is certainly not a place where little green men jump out from behind the rocks." Lee noted, however, that "some of the rocks we saw had details that just aren't explainable by normal lifeless processes. Sometimes it was a thin layer in a cliff that could once have been slime on a creek bottom. Sometimes it was a shape that might have been a solidified track or an impression from a plant. And these were always in the north, where there is more water." Smith said that a more dedicated search for Martian life will be an objective of Argonom residents.

The survey team is confident that Mars offers a wealth of opportunities for future habitation, although they did find one Martian attribute particularly vexing. Mineralogist Lisa Cantu said "the dust is so fine it's called 'fines'. It's not as abrasive as lunar dust, but it's worse at getting into things. Lunar dust gets kicked up and falls right down again. Martian dust hangs in the atmosphere a while. When the wind blows--even at hundreds of kilometers per hour--it's no problem keeping control of the rovers or even standing up outside, because the atmosphere is so thin. But the wind picks up the dust and it gets into everything, at any height. It stuck in the creases and weaves of our suits. It blew into our airlocks with us, and followed us everywhere. It defied every attempt to get rid of it. It reminded me of Colorado River silt in the Grand Canyon--after a week it was in our clothes, in our beds, in our food, everywhere."

Smith said that Argonom is named after the mythological ship Argo, which protected its crew through a series of adventures to far-off places as they fulfilled their quest for the Golden Fleece. "Mars is as remote and dangerous to us as Colchis was to Jason, and we need all the help we can get to make this a prosperous voyage for the Foundation Society."

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-- end -- end -- end --

# Space Settlement Design Competitions

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## Antelope Valley 1997

**Space Settlement Design Competitions** are industry simulation games for high school students, set in the future.

The Competitions emulate, as closely as possible, the experience of participating as part of an aerospace industry proposal team. This year's Space Settlement Design Competition participants will design a settlement on the surface of the planet Mars where over 10,000 people will make their homes.

To help them accomplish this challenging task, each team is provided with a manager from industry to act as Company CEO, and then team members are provided with technical and management training to prepare them for the Competition. They must design an overall structure, define sources of construction materials, specify vehicles used for transportation, determine sources of electrical power and water, design computer and robotics systems, specify allocation of interior space, show examples of pleasant community design, and provide estimated costs and schedules for completion of the project. The Competition concludes with the teams' presentations of briefings describing their designs to a panel of very critical judges.

The experience of participating in a Space Settlement Design Competition teaches young people optimism for the future, technical competence, management skills, knowledge of environments and resources in space, appreciation for the relationship between technical products and human use, ability to work in teams, and techniques for preparing effective documentation. It requires that students integrate their knowledge of and utilize skills in space science, physics, math, chemistry, environmental science, biology, computer science, writing, art, and common sense.

High schools in the Antelope Valley and neighboring areas were invited to encourage their students to participate in this Competition. The event's primary sponsors are NASA - Dryden Flight Research Center, Antelope Valley High School, the Antelope Valley Union High School District, and the Lancaster West Rotary Club .

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National Aeronautics and  
Space Administration  
**Dryden Flight Research Center**  
P.O. Box 273  
Edwards, CA 93523-0273

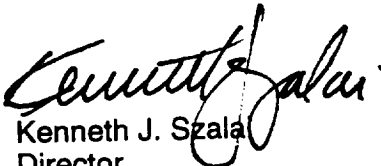


Reply to Attn of: **X**

Welcome to the Third Antelope Valley Space Settlement Design Competition. This competition is designed to challenge you creatively, provide an opportunity for collaborative learning, and to give you a taste of how scientists and engineers work in the real world.

NASA Dryden Flight Research Center is pleased to be sponsoring this event in conjunction with the Antelope Valley Union High School District, The Boeing Company, and the American Institute of Aeronautics and Astronautics. Special thanks are also due to Anita Gale and Dick Edwards of Boeing who designed and developed this competition.

This Space Settlement Design Competition represents just one of the many student programs that have been initiated since Dryden became a Center. However, this Design Competition is probably the most intense, grueling, and enjoyable of any of our education programs. I hope you have a good time, learn new skills, meet new friends, and, perhaps, begin to look at careers in science, mathematics, and engineering in a new way.

  
Kenneth J. Szala  
Director

—

—

—

# ANTELOPE VALLEY UNION HIGH SCHOOL DISTRICT

44811 SIERRA HIGHWAY, LANCASTER, CALIFORNIA 93534 - 3226  
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**September 16, 1997**

**Welcome to the third Antelope Valley Space Settlement Design Competition. It is a pleasure for the Antelope Valley Union High School District to host this competition. Acquiring knowledge is only part of an education. Reasoning, critical thinking, and application of that knowledge are essential to a student's future success. This competition is an excellent opportunity to acquire and practice those application skills. I hope you have a valuable, energetic, and enjoyable weekend.**

**We should all give thanks to Anita Gale and Dick Edwards from Boeing who are the inspiration for this competition. Also, a special thanks to NASA-Dryden and the American Institute of Aeronautics and Astronautics for their sponsorship of this event.**

**Sincerely,**

**Robert Girolamo  
Superintendent**

**v**



# **GREETINGS AND SALUTATIONS!**

This is the year 2047.

You have been called to this meeting because your company is considering bidding on a contract to design and construct an ambitious project on the surface of the planet Mars. The agency that will award the contract is the FOUNDATION SOCIETY, an organization founded for the specific purpose of establishing settlements of its members in space.

**YOUR TASK** this weekend is to design facilities for a **SPACE SETTLEMENT** where thousands of people will live on the Martian surface. Your team must agree on a design that satisfies a set of requirements specified in the Request for Proposal (RFP) defined by the Foundation Society. You will prepare a **35 MINUTE** presentation describing your proposed design, which will be presented by one or more of your team members. The presentation must include dimensioned drawings of your design, and define areas designated for specific activities. You will be expected to justify facility sizes and locations, explain how the structure will be built and populated, estimate cost and schedule for construction, and show systems that will enable the residents to live and work in their new community. At the conclusion of your presentation, members of the Foundation Society will have the opportunity to ask questions about your design for 10 minutes. They will then evaluate your design versus those of your three competitors, and choose a winner.

Successful development of your proposal will require coordination of design details with engineers from four major disciplines in your company. Your company's management has the responsibility to assure that communication is both effective and timely, in order to assure that all of the RFP requirements are met, and that all parts of your design are compatible.

This is much to accomplish in a short time, so **GOOD LUCK!**

## HOW TO PLAY THE GAME

The Space Settlement Design Competition is an industry simulation game that both shows and requires use of corporate communication techniques to get the job done. Your disadvantage is that you have an inexperienced staff--but so do all of your competitors. Some basic skills you need to accomplish the task will be taught in your technical training sessions, and each training session will provide clues for solving a different part of the problem. The **ONLY** way you will get an effective design is for the people in all four of your engineering disciplines to communicate with each other. Every department influences the work of all the others. You must be cautious, however: if you carry communication to the limit, with everybody working on the same part of the problem all at once, you will be wasting time. You need to find a balance between doing the most things at once by having different people doing them, and having people working together to make sure the whole project fits together. Your CEO is a manager where he or she works, and does this all the time. Your President, Vice President of Engineering, and Department Directors will have to learn this quickly. Everybody in your company needs to focus on the common goal, which is to provide a unique design that meets the customer's requirements and is effectively communicated to the judges.

Assuming that you can get your team all working in the same direction, you will win this competition the same way any company wins a proposal competition: **BY SHOWING THAT YOU MEET THE CUSTOMER'S REQUIREMENTS**, and effectively demonstrating this in your presentation.

The managers of your company will receive from the Foundation Society a document, called the Request for Proposal (RFP), that describes **EXACTLY** what the customer wants your design to achieve. Your design should address every issue or point that the RFP includes. You will still have plenty of latitude for innovation in your design, because the customer wants you to figure out the details that will make it work best. But remember to meet **ALL** of the customer's requirements and show that you have done so in the proposal presentation.

You will do best if you also have a good presentation. It is said in industry that you can have the best design in the world, but it is worthless if you can't communicate it. This means that you should be thinking about your presentation and your briefing charts as soon as you start working on your design. Many companies hire whole departments of experts in "chartsmanship" who make sure that the company's designs are portrayed in the most effective manner. Your Vice President of Marketing and Sales is expected to perform this function. Make sure your presentation shows that your design meets every requirement in the RFP.

You also need to do your "homework". The judges will be very critical, and will be looking for weaknesses in your design. Be sure that you know more about it than you have put on the charts, and be sure that **all** of your presenters have a thorough knowledge of why the design is the way it is--and what it is. If one of your presenters calls something a solar dynamic power generator, and the next person calls it an antenna, the judges are likely to notice, and experience has shown that "on the spot engineering" usually only makes it worse.

Although innovation is encouraged, feasibility is essential. Any technologies assumed in your design which exceed those described in the competition materials must be justified (for example, if you plan to use warp drive in your proposal, explain how you plan to achieve it). The judges are engineers working in the aerospace industry, so base your design on reasonable interpretations of the level of existing technology defined by the competition organizers, the laws of Physics, and common sense.

The Competition organizers hope you have a good time in your attempt to win the favor of the judges. We hope you learn a lot, too, because we know that somewhere, right now--whether it be late at night or the middle of the weekend--there are people in industry doing exactly the same thing, but for real money and real jobs. You may join them someday, and this is a great opportunity to learn how the game is played.

GOOD LUCK!

## Just a Few RULES OF THE GAME

The Space Settlement Design Competition is to be conducted **ONLY** with materials and tools available at the Competition site, whether provided by Competition organizers or brought by the participants. No off-site assistance is permitted after participants arrive at the Competition host's facility.

You are working for a Company. Companies do all sorts of things besides creating products, and so can yours. Remember, however, that only a few people can make binding commitments for the company--and if you make a promise or commitment on behalf of your company without your CEO knowing about it, you may be fired. This applies especially to personnel decisions.

A small library of space related technical data will be maintained by the Foundation Society, with books available for one-half hour checkout. The library closes at 11:00 p.m. on Saturday, and all books must be returned by this time.

Food and drink items are allowed in your company headquarters, but you are expected to provide a janitorial staff that will maintain these facilities to professional standards. Companies that fail to maintain a clean and neat working environment (i.e., candy wrappers, uneaten food, stuff that fell on the floor, and trash in general must be deposited in proper waste containers) will be penalized.

Your Company's Proposal Presentation must meet the following requirements:

- Duration no more than 35 minutes (another 10 minutes allowed for judges' questions)
- Use viewgraphs (no more than 30 recommended; fewer preferred)
- Models and/or artwork are permitted
- Back-up viewgraphs may be used to assist in answering judges' questions or to provide supplementary data for the judges' consideration (the judges may only consider these data to discriminate between "tied" presentations)

Your team will have access to copying machines on Saturday only. One copy of all your presentation materials must be turned in to the event organizers not later than 7:30 a.m. Sunday. Event organizers will arrange for making viewgraphs (black on clear only) for your presentation and provide paper copies to the judges. (Any color viewgraphs must be hand-drawn with the viewgraph pens in your supply box, then make a black-and-white plain paper copy to include in your presentation materials submitted at 7:30 a.m. Sunday morning.) Presentations that do not meet the 7:30 deadline **WILL BE PENALIZED**--the later the submission, the more severe the penalty. Return all supplies (drafting tools, pens, etc.) to the event organizers with your presentation materials at 7:30 a.m. Sunday. **FAILURE TO DO SO WILL DISQUALIFY YOUR TEAM FROM THE COMPETITION!**

Originals of presentation materials must meet the following requirements:

- No more than 50 pages may be submitted
- All pages are standard 8.5 x 11 inch white paper, in order not to jam the copier's automatic document feeder
- If you draw something on non-standard paper or viewgraph transparencies, please copy it onto standard paper and submit the copy
- Make sure original artwork will show up on copies (verify pencil drawings are dark enough)
- The first page of your presentation materials must clearly show your company name

Any pages that do not meet these requirements may not be included in the Judges' copies. Only the first 50 pages of your presentation materials will be copied for the judges. The judges reserve the right to **DISREGARD ANY CHARTS NOT INCLUDED IN THEIR COPIES.**

## Space Settlement Design Competition History

Your presence here is part of a long history of Space Settlement Design Competitions.

It all started in 1983, when plans were being made by the Boy Scouts of America for the 1984 National Exploring Conference. The steering group for the Science and Engineering Cluster decided that it would be great to do something neat about space. Only problem was, nobody on the committee knew anything much about space (except that it was neat)—but Evelyn Murray from the Society of Women Engineers knew Anita Gale in California who worked on the Space Shuttle program. What followed was a series of letters recommending ideas and expanding ideas, and concluding with a phone call between Anita in California and Rob Kolstad (a member of the steering group) in Texas. During that phone call, they outlined the basic structure of the event, that it would be both a design competition and a management simulation game. Anita recruited her friend and fellow-volunteer-for-many-things Dick Edwards to help write the materials for the game, and the rest, as they say, is history. The first Space Settlement Design Competition was conducted at Ohio State University (between thunderstorms and tornadoes) in August 1984, with about 75 participants. It was wildly successful. Even astronaut Story Musgrave stopped by to watch design presentations.

The Explorers' Science and Engineering Cluster was so impressed by this event, they started working hard to make sure it would continue in some form. Eventually, Dr. Peter Mason and the Space Exploration Post at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, agreed to try it out on a local level.

The first SPACESET was held in 1986. Twelve annual SPACESET competitions have been conducted at JPL, with continuing participation by Anita Gale, Dick Edwards, Rob Kolstad (who now flies in from Colorado), and Peter Mason. As many as 160 young people participate each year, with a different design challenge each time. The competition organizers have requested Space Settlement designs in Earth orbit, on Earth's moon, on and in orbit around Mars, and on and in orbit around Venus (including some global atmospheric alterations to make the place habitable). One Earth orbiting Settlement was required to be able to move to another solar system; another solved a global warming crisis.

The first annual National Competition was organized when SpaceWeek International considered that a Space Settlement Design Competition would be appropriate to include in commemorating the 25th anniversary of the first lunar landing, in 1994. Astronauts and Cosmonauts recruited as volunteers for this event were so impressed with its educational value, they insisted that it be continued annually. Although it soon became evident that SpaceWeek International was unable to sponsor subsequent National Competitions, the promise made by Anita and Dick was accomplished in 1995 at Epcot in Walt Disney World, and the Third Annual Finalist Competition moved to an apparently permanent home at Kennedy Space Center in 1996. Any high school in the world is welcome to join International Qualifying Competitions, by accessing materials on the Internet at <http://space.bsdi.com>.

The concept has grown. The annual Antelope Valley Competition started in 1995 when Max Vallejo of Rockwell (now Boeing) learned that NASA-Dryden Flight Research Center desired to offer enhanced educational experiences to local students. A proposal to conduct a JPL-type Competition was submitted to Lee Duke, Education Functional Manager for NASA-Dryden, who authorized the event. In 1996, NASA-Dryden enlisted the help of Victor Valley College and the Apple Valley Science and Technology Center, to establish a similar Competition in the Victor Valley.



## REALITY VS. Space Settlement Design Competition

A statement you may hear several times during your Space Settlement Design Competition experience is "Now you know what it's like in industry!" This is, after all, an industry simulation game. You will have too much data in some areas, too little in others, not enough time to search out what data are available, personnel conflicts in your organization, technical conflicts between departments, difficulty in describing your entire design during the time allowed, and questions from the judges that you consider unfair (or "I forgot" revealed). All of these are challenges faced by real engineers in real companies (and have been faced by many of the adult volunteers you will meet). Of course, a lot of the Space Settlement Design Competition is pure fabrication: it describes, as history, things that haven't happened yet. So, what is real, and what is Design Competition speculation?

The basic products, vehicles, and structures described for the Space Settlement Design Competition are technically possible, within the timeframes indicated. They do, however, represent ambitious technical, economic, and political commitments. Some will never happen, some will. Some are projects that Design Competition participants who become engineers will work on during their careers.

The Design Competition companies, including their product lines and histories, are based on composites of real corporations, projected into the future. No Competition company, however, is based solely on a single real company. Company names were selected for humor and name recognition, and do not indicate any similarity to real corporations. The recommended Design Competition organization chart is a true reflection of part of a generic organization structure used by many companies.

There is no such organization as the Foundation Society (too bad!). The described efforts by the Foundation Society to foster commercial space infrastructure development could, however, be accomplished by other existing organizations.

The Request for Proposals and proposal process reflect, as closely as possible, the system by which real corporations propose and win contracts for new business.

Information about space, lunar, and planetary environments and resources is based on numerous references. Supplementary articles and other materials are genuine technical documents that have appeared in print, or were specifically prepared for the Design Competition but are based on serious research. Sources are clearly marked where possible, and have not been fabricated. "Department Descriptions" represent a summary of the types of tasks, analyses, and factors that similar real groups address.

Descriptions of specific future commercial products manufactured in space, space-based businesses, and health benefits of life in space are pure speculation.

Described missions to Mars do NOT reflect feasible mission dates, based on ephemeris data for the years described. Although it is theoretically possible to launch missions to Mars from Earth at any time, vehicles that depart Earth's vicinity at other than optimum Hohmann Transfer opportunities will require significantly more energy (fuel) and time to complete the journey.

The difficulties associated with Martian dust are real. The stuff is incredibly fine, gets into everything, has defied all attempts to completely remove it from anything that has been outdoors, and will ultimately destroy any mechanical equipment it gets into. Long-term habitations on Mars must take every grain of tracked-in dust very seriously, because a gradual accumulation over time could result in some very serious problems.

If, during this experience, you have any questions about the aerospace industry, feel free to ask your company's CEO or another adult volunteer--many of whom do the same things in real life that you have the opportunity to do here.

## HOW COMPANIES WORK

Projects as huge as the Space Settlement being designed for this competition are excellent examples of how large companies came into being.

For most of human existence, the things that people made and used could be produced by individual people, or by small groups of people who worked together as partners. Those items that were in broad use could be made separately by many such individuals or small groups in many locations; products like shoes, houses, weapons, wagons, and food products are in this category. Indeed, technology has usually been simple enough that if a product was required in a place, somebody could be found nearby who could replicate it. Many things that we now buy for personal use are things we might have made for ourselves only a hundred years ago—things like bread and other prepared foods, soap, candles, and clothing.

Exceptions to this "rule of small-group manufacturing" were large public works projects: government buildings, aqueducts, roads and street networks, city walls, bridges, and even cathedrals and temples. Through necessity for the public good, construction of these structures was controlled through government (including military) or church bureaucracies. These projects were, after all, too important to be left in the hands of private individuals, construction time was often longer than an individual's lifetime, and only a government or church had a large enough organization to have influence over the geographic locations and large numbers of people that were involved in supply and construction.

Advances in technology changed all of this. Products came into use that could only be made by machines, machines were developed that could do work better and more quickly than muscle, and quality could be achieved more consistently with machines. As these machines became more complex, they could not always be replicated by somebody in the local area. The small groups of people that could make them got requests for more and more, and from all over the nation and the world. Greater demands for the products meant that these organizations were encouraged to grow so that they could meet the needs of their customers—and many of these organizations became large corporations. The advent of these giants then made it possible for single organizations to complete huge projects, including skyscrapers, supertankers, supercomputers, jumbo jets, giant rockets for launching tons of payload into space, and even entire cities in the Middle East. When companies find that they do not have all of the people or facilities required to perform such feats, they team up with other companies to combine resources.

As organizations grew, they had to adopt new ways of doing business. The boss no longer knew everybody, directed each person's work, and worked right alongside the employees. Whole new careers and kinds of work had to evolve. Work was divided into that which was done by the managers, and that which was done by the common laborers. Administrative positions developed to handle finances, hiring, advertising, and even making sure everybody got a paycheck. Companies found themselves in a situation where they could have a perfectly good product, and still fail—through faulty management.

As this was occurring, there were no historical precedents to guide the participants. Their primary priority was to get the products out the door, and on-the-spot innovation was used to form an organization that could do the job. Under the circumstances, the organizations that evolved adopted patterns that were familiar to the people who were arranging them—military patterns that had been used for millennia to coordinate the efforts of huge numbers of people. This worked reasonably well in early corporations, because the intelligence to run the business resided at the top, and the other folks could do their jobs adequately just by following orders.

In only the past few decades, the nature of the products produced by large corporations has been changing, and their organizations have been evolving to adapt. To stay in business, corporations

must now rely on the intelligence of employees at all levels--not just at the top. Strategic planning, corporate philosophies, and competitive positioning are still defined by top executives, who must make sure that the lower echelons understand their duties to implement them. These top executives must also make sure that they have good communication up from the lower ranks, so that they know what is going on--especially if a problem arises that demands high-level attention. The greatest changes are occurring at the bottom rungs of corporations, where the population is becoming dominated by "knowledge workers" instead of common laborers. These include researchers, product designers, and computer programmers who determine the very nature of the products that can be offered by the corporation.

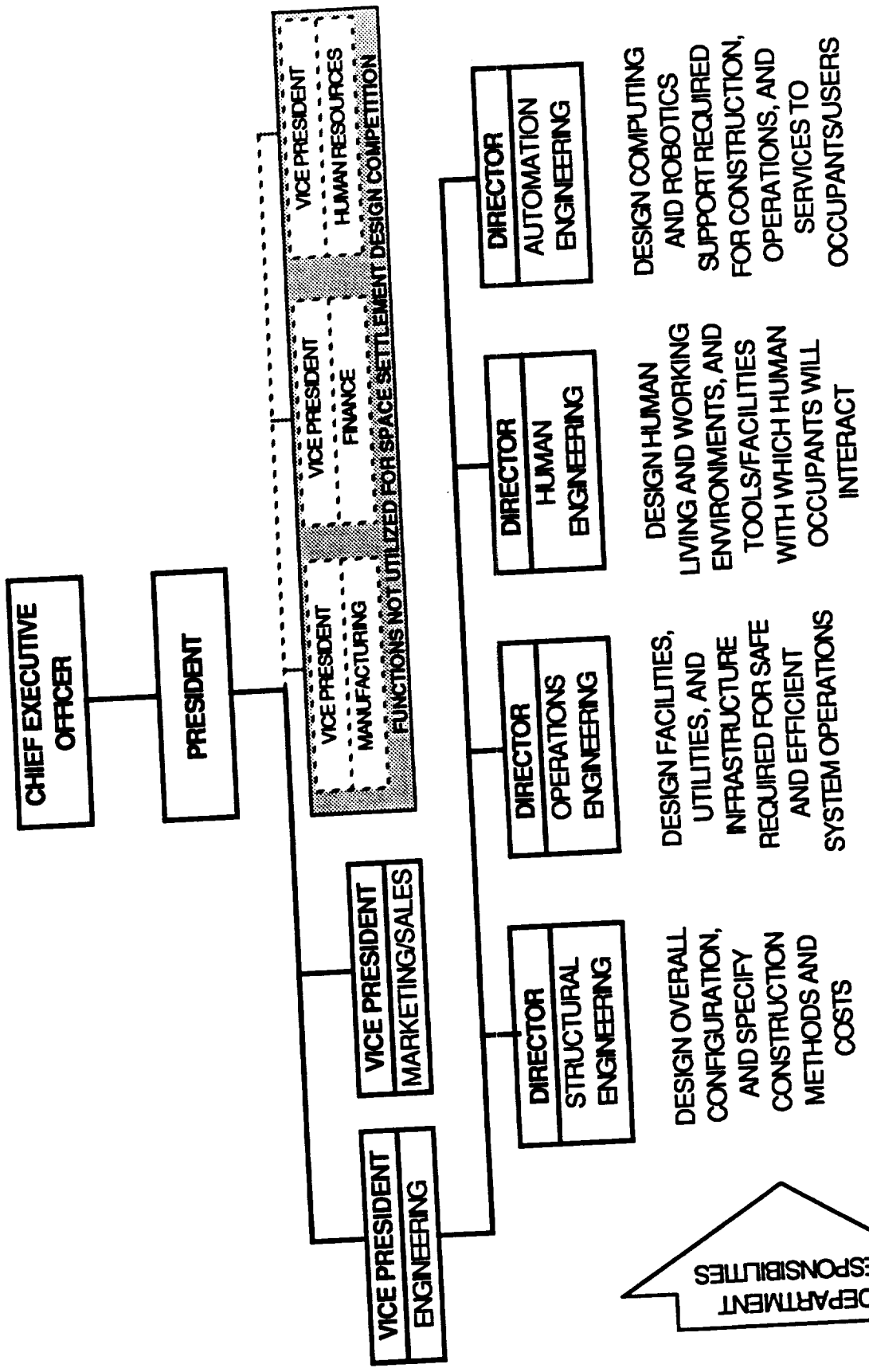
The whole science of management is changing to accommodate this new type of employee. It includes recognition that communication is the lifeblood of the organization, each individual employee has unique skills to offer, employees at all levels are more productive if they enjoy their work, and employees enjoy their work best when they feel it is important.

Communication is the greatest challenge faced by top management. The sheer size of some organizations illustrates the problem. A typical organization has a small group of officers including the Chief Executive Officer, Chief Operating Officer, and Chairman of the Board; reporting to these are Division Presidents, to whom report some Vice Presidents, Directors, Managers, and Supervisors. Below the Director level, eight to fifteen individuals of the next lower rank may report to the higher level. A Vice President-Engineering for a very large division may have five Directors, 50 Managers, 600 Supervisors, and 9000 engineers and other technical people. Employment of 10,000 to 20,000 individuals at one plant is not uncommon. Some corporations have dozens of divisions world-wide, and employ hundreds of thousands of people. Even in the same building, everybody does not know everybody else. Effective operation of the corporation requires, however, that people working on different parts of a project share information about it. Sometimes a problem on one project can be solved by a person who has had similar experience on another project. The "perfect solution" has not been found, and companies still find themselves making parts that don't fit, designing products that can't be maintained, creating destructive software, and even forgetting to complete contracts.

Professional people are also expensive. Typically, a company pays \$125,000 to \$150,000 each year for the salary, benefits, floor space, furniture, supplies, repro machines, utilities, telephone service, and other overhead to support one engineer. "Overhead" includes secretaries, janitors, guards at the gates, the fire department, the first aid station, and the computers.

This all seems very intimidating to the individual who has just accepted a first job in a huge corporation. Fortunately, most modern corporations are friendly places where new employees are helped to adapt as quickly as possible--it does, after all, help the company to make you productive with minimum delay. There are several phases to this absorption of new employees. On the first day, your primary interest is to figure out how to find the (correct) restroom, the route from your desk to the door of the building, the route to the gate of the plant, and how to find your desk from whatever location you find yourself in when you realize you are lost. Your first work assignments will be relatively straightforward tasks you were hired to do. If you get stuck, you will find lots of other people in your group, including your supervisor, who will show you "the company way" or the right people to help you accomplish your tasks. After one to five years, your performance on projects will lead to your establishing your niche in the organization, and in four to ten years you could become an expert in your field. In all of your work, you will become more valuable as you know and are known by more people with other special skills or knowledge.

# COMPANY ORGANIZATION CHART



DEPARTMENT RESPONSIBILITIES

## **Space Settlement Design Competition STANDARDS OF PROFESSIONAL CONDUCT**

The NASA - Dryden Flight Research Center and Antelope Valley High School have generously allowed us to use their facilities for the weekend. In return, they have established some guidelines that we need to follow while we are here:

1. Smoking is not permitted inside any buildings at Dryden Flight Research Center or at the High School. Consumption of alcohol is not allowed at any time during the weekend. Design Competition participants are expected to abide by all laws enforced in the city of Lancaster.
2. Leaving the Competition sites during the weekend is strongly discouraged; only participants who have turned in a Home Permission Form signed by a parent will be allowed to leave the Competition before it ends. If you find it necessary to leave the Competition during the weekend, you must check out either with the Registration Desk, or with a staff member on duty at the High School gym during the night. If you leave without checking out, we will assume that you have forfeited your place in the Competition.
3. Dryden Flight Research Center operates seven days a week. Do not venture out of the areas designated for Design Competition participants.
4. You may encounter equipment operating unattended. Do not touch any equipment that has not been allocated to the Space Settlement Design Competition. If you are not sure if a piece of equipment is intended for use by the Competition, please ask a staff member.
5. Eating and drinking are not permitted on the main floor of the gyms. Please ask a staff member where eating and drinking are allowed indoors.
6. Participants desiring to remain awake after the lights go out in the gyms should go to an area designated by a staff member on duty at each gym. Out of courtesy to those who wish to sleep, please try to keep the noise level down. NOTE: your company headquarters will be available for your use all night long Saturday night / Sunday morning; while you may continue to work on your company's presentation after returning to the gym on Saturday night, your company's computer equipment may not be removed from your company headquarters.
7. Separate sleeping quarters are provided for the guys and the gals. Guys are not allowed in the gals' sleeping area, and vice versa.
8. Competition staff members will be available at all times, either at the Registration Desk or in the gym. If a circumstance arises that is not explicitly covered by these guidelines, please ask a staff member, and/or use common sense in your choice of actions.

**Remember, you are a professional now.** Your cooperation in following these guidelines is greatly appreciated. Your responsible behavior will enable use of these facilities for future Space Settlement Design Competitions.

## SPACE CHARACTERISTICS AND RESOURCES

Space is not a friendly place. Mostly, it is nothing: vacuum, and apparent lack of gravity. What little there is in space is mostly hazardous, even the things that are assets.

One asset abundant in space, at least out to Mars orbit, is power, in the form of energy from the Sun that can be converted into electricity. The supply of power from the Sun is continuous and uninterrupted, and it is 6 to 15 times as intense in Earth orbit as on the Earth's surface (solar energy intensity is absorbed by Earth's atmosphere). Solar energy does, however, present hazards, in that it is harmful to humans who are not shielded from it. The Sun is also the source of flares producing intense radiation which is deadly to unprotected humans. The Sun is not the only source of hazardous radiation in space; cosmic rays, gamma rays, and X-rays are also part of the ambient space environment, at sufficient intensities to be damaging to humans.

The primary law of space is Orbital Mechanics, which determines where things can stay and where they can go. Everything in space is moving, attracted by gravitational fields (usually interacting) of every major object in the vicinity. Which orbit an object is in depends on its position and velocity at any particular time. Orbits are changed with acceleration due to thrust, usually from rockets. Satellites are constrained to be far enough above most of any atmosphere that an orbit can be sustained with minor altitude decay due to friction with the atmosphere. Objects with bigger cross-sections experience faster orbital decay. Higher velocities put objects in higher orbits; an object achieving "escape velocity" (25,000 mph for Earth) will leave the influence of its "host", and go into orbit around something else. Orbits are also not perfectly stable. Satellites use small rockets for "station-keeping" to stay where desired. Some quirks of orbital mechanics cause gravitational forces of large bodies to be in balance at some locations, creating "Libration Points" that are either very stable (L4 and L5) or are unstable in one plane (L1, L2, and L3), and require substantial station-keeping to maintain spacecraft in position.

Solid objects in space are also both hazards and assets. Debris is a nuisance: at orbital velocities, even paint flecks can do damage, and small bolts or rocks can puncture spacecraft cabins. The Moon and asteroids, however, represent vast reserves of relatively easily accessible resources; getting to them requires much less energy than launching materials from the Earth. The lunar surface is 99% oxides, of silicon, iron, aluminum, calcium, magnesium, and titanium. Asteroids are of several types, and can contain nickel, iron, water, carbon, and carbon compounds. Comets typically move faster and are harder to capture, but contain substantial reserves of water ice.

There are some similarities between Mars and Earth. Martian days are just 37 minutes longer than days on Earth. The surface area is nearly identical to the land area of Earth. There are many land features (mountains, valleys, cliff faces) like familiar ones on Earth, although the most spectacular are ten times taller, wider, and deeper than their Earth counterparts. Resources are abundant: the Martian atmosphere, though less than 1% the density of Earth's, is 95% carbon dioxide and almost 3% nitrogen. Water ice is present in the North polar cap, and surface components include silicon, aluminum, iron, magnesium, and calcium. There is, however, an eerie otherworldliness about the place, too. There is gravity, at 38% of the force on Earth's surface. The sun is pale and cold, providing only 36% of the energy available for the same area of solar panels in Earth orbit. The two moons are tiny and close; one crosses the sky three times per day. There are seasons, in a year nearly twice as long as Earth's, with a much harsher climate in the southern hemisphere. There is a South polar cap, but it consists of carbon dioxide ice. The surface environment is hardly more hospitable than empty space. It is cold on Mars, with an average surface temperature of -60°C, and the warmest temperature barely above freezing. The radiation hazard is nearly the same as in space, because the negligible magnetic field and thin atmosphere offer little protection. Winds that blow up to hundreds of miles per hour can hurl dust with sandblasting ferocity, and cause global dust storms that last for months.

## EXISTING SPACE INFRASTRUCTURE

Earth orbit in 2047 is a very busy place, with thousands of automated satellites serving the seemingly insatiable appetite of the terrestrial population for communication, navigation, observation, materials processing, manufacturing, energy, and tourism.

Most of the demand for satellite locations has been in geosynchronous orbit, where even the closer spacing allowed by improved signal separation technology in the late 1990's did little to relieve the competition for communication satellite "slots". Resolution of this problem was finally achieved with the development of geosynchronous antenna "farms" up to a kilometer long, each of which supports equipment that would otherwise have required dozens of separate satellites. Solar Power Satellites are not subject to spacing restrictions, and occupy GEO between antenna farms.

Low Earth orbit is primarily occupied by resort hotels and successors to the original three Space Stations (now spaceports) established by the United States and some international partners after the year 2000. Regular passenger and cargo service is available to all three ports from eleven locations on Earth's surface, with launch costs, including insurance and payload integration costs, averaging \$600 per lb. for first-time payloads, and \$550 per lb. for repeat payloads. The spaceports are at 250 miles altitude; most launch vehicle traffic from Earth still goes through these ports, where goods and passengers are transferred to ships more appropriate for operations in space. Several other large orbiting spaceports have been established between 55,000 and 100,000 miles altitude, to provide satellite maintenance and construction services. Space tugs are available to move satellites between orbital locations

The largest orbiting space operations are the settlements established by the Foundation Society, which have been placed in orbits around the L5 and L4 libration points. The Settlements provide safe and pleasant living and working environments for communities of 10,000 to 20,000 full-time inhabitants each, and up to two thousand visitors. The inhabitants are fully employed maintaining and operating their Settlements, and producing products as needed by the communities and for trade. The orbiting Settlements have port and cargo-handling facilities that are available for transferring goods and materials between ships. Alexandriat was expanded from its original design, and a decade ago founded the University of Space Science and Technology, to service the research and higher education needs of the growing spacer population.

The first lunar outpost was established with missions using spacecraft assembled in orbit with components launched on two different Reusable Launch Vehicle (RLV) flights, in the year 2008. During the next decade, two other bases began operation, each with a staff of between six and fourteen people. Their exploratory expeditions confirmed both the abundance of lunar minerals and oxygen compounds, and the near absence of hydrogen, nitrogen, and carbon. Although water ice was found in deposits in the eternal shade of a south polar crater, the quantity was insufficient to sustain large-scale human operations. The Foundation Society is leading large-scale Lunar development, having established a surface settlement for 8000 residents, with facilities for up to 2000 visitors. A second settlement began occupation in 2041. Regular passenger and cargo service is available to the two Foundation Society sites on the Moon.

Despite successful completion of manned missions to Mars in 2019, 2016, 2030, and 2034, and 15 years of mining operations in the asteroids between the orbits of Mars and Jupiter, only the Foundation Society has demonstrated an interest in establishing a large-scale human presence on the planet's surface. Although the Aresam settlement will not be ready to support large-scale surface activities until 2052, it has been providing expanding services to asteroid mining operations since 2044, and serves as a base for the Foundation Society's ongoing small survey missions to the Martian surface.

## THE CUSTOMER

The FOUNDATION SOCIETY is an organization founded for the specific purpose of establishing settlements of its members in space. In the mid-1990's, it led several grass-roots space advocacy organizations in fostering development of commercial infrastructure in Earth orbit, by researching profit potential for launch vehicles providing lower costs per pound to orbit. The Society assured that new launch vehicles would have customers, by providing venture capital for companies developing new products that utilized or required launch services. The Foundation Society funded lobbying in Congress that resulted in favorable tax and equity-protection laws for companies investing large percentages of their assets in perceived high-risk ventures with long-range return, further assured a strong customer base for commercial launch services with long-range commitments for government-sponsored scientific and exploratory space missions, and removed the government from the businesses of launch vehicle operation and space hardware fabrication. The results of these efforts encouraged American corporate interest in commercial development of the launch vehicles and space infrastructure that have made large-scale access to space practical.

The Society began operation of its first settlement for 10,000 of its members in Earth orbit late in 2012. The second Foundation Society orbiting settlement began occupation in 2022, and a third began occupation in 2030. Since that time, two settlements on the lunar surface have been completed (2027 and 2041), and a settlement is nearing completion in Mars orbit. Plans are in various stages of development for more large space settlements; this expansion of infrastructure will continue as long as promising new sites are available, and economic reality permits. The Foundation Society intends that each community eventually be self-supporting through trade and services it can offer to Earth and other bases and settlements. [Note: the Foundation Society has established a convention for naming the new communities it creates, allowing initial residents a personal choice in selecting names for their cities, yet providing some traceability of place and history. A suffix indicates location, and communities with the same suffix receive names in alphabetical order. Hence, the three Earth-Orbiting settlements were named Alexandriat, Bellevistat, and Columbiat ("at" = "(in orbit) around Terra"). The two communities on the lunar surface are Alaskol and Balderol ("ol" = "on Luna"). The first settlement in Mars orbit is "Aresam". For contract award purposes, the first Mars surface settlement is called "Argonom", although its occupants have not yet been selected and the name has not been finalized.]

Although the Foundation Society has developed sufficient financial reserves to invest in expensive projects like Space Settlements, the organization's goal is to build as many as possible, and therefore to develop an efficient construction infrastructure. To this end, lunar materials have been utilized extensively in the existing settlement designs. Lunar concrete has proven to be an excellent shielding and building material when used in compression applications. A high-quality lunar glass is made in Foundation Society facilities at Columbiat; although it does not provide shielding, it has superior optical characteristics and carries both compression and tension better than Earth-supplied equivalents. An iron-nickel asteroid was delivered to Bellevistat, and harvesting operations are currently processing several tons of ore per day.

Members who occupy each settlement have earned the privilege through substantial investments of financial resources, frequently in combination with contributions of property, materials, capital equipment, and services. Most of the individuals who have been able to afford Foundation Society membership have acquired their wealth either through family resources, or through successful entrepreneurial enterprises. Those who have augmented less substantial financial resources with "intelligence equity" are primarily professionals, with a high percentage of engineers, scientists, and technicians. Some residents of existing settlements are operating businesses there; their products are almost exclusively "soft goods" that can be transmitted by data link (e.g., software, research results, text).

Most of these people are Americans; the non-Americans in the Foundation Society's existing and planned communities have either lived or traveled extensively in the United States. A primarily American culture prevails in the current Foundation Society communities, although each settlement has acquired its own unique personality.



## **DOUGELDYNE ASTROSYSTEMS**

Located in Bellflower, California, Dougeldyne AstroSystems is the world's most prolific manufacturer of unmanned space systems. With humble beginnings as a builder of aircraft parts and industrial tools, the company entered the spacecraft business in the early 1960's with a reputation for quality manufacturing of specialized products, and a few key employees.

Although Dougeldyne built the whole gamut of unmanned satellite systems, for military, scientific, NASA, and commercial customers, the company's reputation in the aerospace industry was primarily established through its development of communications satellites. Since the 1980's, the company has offered satellites designed for different parts of the space communications market. Upgrades usually kept these products slightly ahead of competitors' technology developments, with new generations of capability available every four to six years. Indeed, the company's rapid technology improvements were largely responsible for the industry's recognition in the mid-1990's that satellite "slots" were more valuable than the satellites themselves. Satellite construction costs were subsequently reduced by a factor of three through reduction of redundancy and robustness. Dougeldyne did pioneering work in development of antenna "farms", and was prime contractor for construction of four of these projects. The company now builds, installs, and services many of the communications systems that are installed on the antenna farms.

A spinoff from Dougeldyne's satellite business was a very successful research program in solar panel technology, which the company capitalized on in winning the contract to develop the solar power system for the first International Space Station. A breakthrough in solar cell efficiency reduced required solar panel area by half, new materials technology extended average solar panel lifetime on orbit by six years, and cost per watt was reduced to 30% of that previously required through innovative improvements in production efficiency. Since 2018, Dougeldyne has been producing space-quality solar panels for \$50 per kilowatt in its lunar-orbiting manufacturing facility. The company thus established itself as the primary supplier of solar panels for spacecraft and space-based systems, and maintains this position with a vigorous and successful research program.

Improvements in solar panel fabrication techniques reduced production costs enough to justify construction of company-owned Solar Power Satellites beginning in 2006. The company built a 100-megawatt prototype, but was unable to attract customers for larger versions when problems developed with the equipment that converted the collected power into microwave energy for transmission to users. Although this challenge was eventually solved, large utilities remained unimpressed. Dougeldyne continued with the project anyway, and began selling surplus power from a two-gigawatt installation completed in 2011 to the same "dirtside" utilities that refused to support it. Subsequent Solar Power Satellites have been built to supply Foundation Society settlements and other large on-orbit facilities. Completion of the Lunar Polar Power Plant in 2025, and the company's willingness to expand its power-distribution infrastructure to support customers' projects, enabled significant cost and complexity reductions in the designs of the Foundation Society's Alaskol and Balderol settlements.

Dougeldyne is also a provider of launch and orbital transfer services for space cargo, having recognized that its dependence on the availability of other organizations' launch vehicles and launch sites had the potential to jeopardize its ability to sell satellites. The company owns a modest fleet of launch vehicles and space tugs purchased from Grumbo, and operates a launch site on a large platform at the Equator in the Pacific Ocean. A small fleet of ships transports payloads from San Diego, California, to the launch facilities.

Dougeldyne executives aggressively sought--and won--the Columbiat contract as a means to break into the manned spacecraft market, after they became concerned that the company's concentration on unmanned satellites could be detrimental in the future business climate. The company is teamed with Flechtel Constructors to make up for its lack of expertise with human factors and expects this partnership to be a strong competitor for the "Argonom" contract.

## FLECHTEL CONSTRUCTORS

Although its corporate offices are formally located in New York City, Flechtel Constructors has offices in cities around the world, which operate nearly autonomously.

The company has been in business since the 1920's, when it designed and built facilities for energy and chemical companies. Until the late 1960's, Flechtel products were primarily oil refineries and factories producing industrial chemicals, fertilizer, and household cleaning products. The company has skills, however, for designing nearly any industrial, commercial, or government facility, and has been involved with concepts for power plants, ground transportation infrastructure, farming, logging, amusement parks, harbors, and airports. In the 1970's, the company was known for its contracts to design entire cities in the Saudi Arabian desert, including airports and water desalination plants. Flechtel expanded rapidly during the 1990's with contracts to upgrade Russian and Kazakhi oil industry and petrochemical plants, modernize the ground transportation infrastructure of Russia, Ukraine, and (European) Georgia, clean up environmental damage in Eastern Europe and Northern Asia, and rejuvenate several Eastern European cities. In the 2010's, Flechtel designed and built the Kenyan veldt launch site and Dougeldyne's Pacific Ocean launch site, and has since assisted with upgrades to these facilities to accommodate new launch vehicle designs. A large percentage of its business in the 2020's resulted from its leadership in developing designs for modifying airport facilities to service aircraft with cryogenic fuels. A consistent company philosophy is that every customer is important, and no project is too big, too small, or too strange.

Low-cost and high-quality construction techniques, developed during the post-Soviet construction boom, were applied after the year 2000 to bring about rapid development in developing countries. The company began assisting poor nations by entering into joint ventures to develop capital-earning industrial bases through construction and operation of factories exploiting each nation's workforce skills and natural resources. Successful operations of these ventures are assured by Flechtel employees who stay with the plants through start-up, conduct training programs for local workers, and periodically return to see that no problems are developing, and to introduce improvements in plant operations. This program so greatly benefited developing nations that Flechtel was awarded a Nobel Peace Prize in 2011.

The company again gained humanitarian recognition in the 2030's, when it developed a design and demonstrated feasibility of operating huge ocean farming systems. Other companies have since developed their own designs for these facilities, and now dozens of them are operating in remote deep-water areas of the Pacific and Indian Oceans, far from land and pollution. Isolation from contaminants enables farm operators to better control nutrients provided to fish and aquatic vegetables, and to better control diseases. The development of these farms has assured virtually inexhaustible food supplies for Earth's peoples.

Flechtel has been associated with the aerospace industry since the late 1980's, when it assisted Grumbo Aerospace with some research into requirements for construction of human habitats on the lunar surface. This work was of very high quality, defining standards for light filtering and radiation shielding for different types of human activity on the Moon. Flechtel has since been involved in some way with every lunar habitat construction project. As a subcontractor for the U.S. lunar bases, the company designed and constructed living area interiors, and was more successful than other companies in developing dust control systems. Flechtel engineers did conceptual design for port facilities at the Foundation Society's Alaskol settlement and built the extensive tourist facilities adjoining Balderol. The company worked on a major contract from the U.S. government to do advanced studies of lunar infrastructure requirements.

Flechtel is currently teamed with Dougeldyne AstroSystems in the competition to build the Foundation Society's "Argonom" settlement, reviving a relationship that won the contract to build the Foundation Society's Columbiat settlement. Dougeldyne's experience with orbital systems provides a strong complement for Flechtel's experience with habitats on the lunar surface.

## **GRUMBO AEROSPACE**

Grumbo Aerospace, a division of Grumbo International, is located in Augusta, Maine. Aerospace is one of Grumbo International's four major business groups.

Products of the General Industries business area include F1M8 Robots. Although they service a variety of commercial and domestic applications, F1M8s all share a proprietary "artificial intelligence" capability that enables them to recognize commands in human speech and "learn" through experience. In 2042, Grumbo upgraded robotic operations at the Foundation Society's lunar mining facilities; when the new robots harvest the ore, they extract and process materials from which they produce ore-carrying cars that transport raw ore to the primary refinery and distribution center. In this operation, the cars themselves are actually a pre-processed part of the mined shipment.

Among the achievements of the Electronics Systems Group was development of the chips and software that enable billboard companies to reprogram displays on any of their roadside billboards anywhere in the world from one central command location. This capability changed the sign industry; some billboards are completely changed several times per day, according to anticipated demographics of travellers on adjacent roadways. The company also pioneered computer file technology that changed the way documents are filed in offices; paper copies of reports and documents are now virtually nonexistent, since Grumbo's development of circuitry for computer disk "file cabinets". These resemble old-style 5-drawer cabinets for paper files, and remain inert (draw no power) until the user requests a file--at which point only the "drawer" containing that particular file in the "file cabinet" is activated and accessed by the user's computer.

The Ground Transportation Group successfully transitioned to supply products for the first Ground Effect Machine personal vehicles and magnetic engines. This segment of the company also built several vehicles customized for operation on the lunar surface, with technical assistance from the Aerospace division. Grumbo vehicles are in use at the Alaskol and Balderol settlements, and are utilized for exterior (primarily maintenance and repair) tasks on all of the Foundation Society's orbiting settlements.

Early products of Grumbo Aerospace included expendable launch vehicles (ELV) and upper stages to transfer payloads from low Earth orbit (LEO) to geosynchronous Earth orbit (GEO) and other high-altitude orbits. ELV markets dwindled after 2010 and disappeared by 2020; the company ceased production of upper stages in 2026. The ELV and upper stage production facilities were, however, re-tooled for building components of orbital transfer vehicles and space tugs; the components are launched to Grumbo's LEO factory, where they are assembled into vehicles optimized for operating in space.

The company's most well-known product is the Reusable Launch Vehicle (RLV), which began service in 2006; this was the first commercial vehicle based on X-33 technology. The vehicle launched up to 25,000 lbs. to the existing spaceports, and 43,000 lbs to 160-mile LEO. This 200-foot-long vehicle also pioneered development of the 45 foot long by 15 foot nearly square cross-section space cargo containers now standard for all medium-size launch vehicles. RLV was briefly threatened by competition from the more economical Condor, built by Vulture Aviation, when it entered service in 2013--until commercial operators realized that there was plenty of launch business for fleets of both vehicles. Grumbo also developed the "Grumbo Jumbo", a heavy-lift reusable Single Stage to Orbit design (up to 100,000 lb. payload) that captured a significant share of the commercial cargo market when it went into operation in 2017. The Grumbo Jumbo tapped into a huge market for space-based disposal of hazardous wastes, which became lucrative with launch costs below \$500 per pound. Grumbo now sells several different versions of both vehicles, with RLV capability up to 55,000 lb. to the spaceports, and Grumbo Jumbo capability to 175,000 lb.

Grumbo participated heavily in early space settlement studies and independent research. This commitment was a significant factor in the Foundation Society's selection of Grumbo to build Bellevistat, completed in 2022, and Balderol, which began occupation in 2041. Company officials feel they have established a reputation with the Foundation Society that puts them in a good position to win the "Argonom" contract.

## ROCKDONNELL

Corporate Headquarters were moved to an orbital location dubbed "Rock-in-the-Sky" in 2020, in order to be closer to where the company does business in Earth orbit. Rockdonnell was formed as a joint venture between two major firms, for the purpose of winning the first Foundation Society Space Settlement contract.

Rockdonnell did win the first Foundation Society Space Settlement contract, and in 2012 successfully completed Alexandriat. The company continued its relationship with the Foundation Society with completion of Alaskol in 2027. When the Foundation Society decided to modify and expand Alexandriat in the late 2020's, Rockdonnell created the designs and managed the construction process.

One parent company is a large and successful aerospace firm with several divisions. Spacecraft built by the Spacets Division include asteroid retrieval hardware utilized by Bellevistat's highly successful mining operation, zero-g refineries for extraterrestrial materials, and small Mars landing vehicles based at Aresam and used for the Foundation Society's planetary surveys. The Rockonetics Division is the major producer of engines for the aerospace industry, having established its reputation by developing the first air-breathing engine that could honestly achieve Mach 25 in the upper atmosphere, which ultimately resulted in Vulture Aviation's Condor launch vehicle. The Compsec Division produces 15% of the supercomputers used by the aerospace and entertainment industries, and has just introduced the third in a line of "micro-abacus" computers, advertised as fast, rugged, and transportable. An especially appealing feature of these machines is that they can be customized to fit particular applications; they are built up of small modules that can be separated or combined to provide capabilities ranging from workstations to sophisticated mainframes.

The other parent company is a large diversified firm with interests in oil, real estate, and hotels. It also leases communications services to governments of two dozen developing countries, through communications facilities it owns on six antenna farms.

Several Space Station experiments owned by the aerospace parent company led to identification of promising space manufacturing opportunities. These were offered to other corporations by Rockdonnell on the condition that Rockdonnell design, and build on-orbit space factories for commercial production of these products, and that 2% of profits from these operations be paid as a royalty to Rockdonnell. This venture has been very successful, with dozens of space facilities manufacturing pharmaceuticals, electronic components, genetically engineered organisms, and other high-value, low-weight-and-volume products; more are under construction or in the planning stages. This capability is especially attractive for genetic engineering projects, which are prohibited by many nations on Earth that fear ecological damage if a process goes awry.

With Rockdonnell's success, the two parent companies have frequently embarked on other joint projects. The most well-known of these is Icarus Inn, a private spaceport and resort hotel in Earth orbit that opened in 2013. The company used very aggressive marketing strategies to establish a public image for providing the ultimate in "status" vacation opportunities. All of the private suites are designed to provide stunning viewing of Earth below, and cater to guests' preferences to stay in zero-g, one-g, or intermediate acceleration environments. The venture proved successful, inspiring Rockdonnell to develop the more opulent Daedalus Resort that opened in 2025, and the family-oriented Helios Habitat which started entertaining guests in 2033. Since then, the company has opened a new on-orbit resort every five years, and plans to continue developing new properties--each with a different theme or guest demographic target--at five-year intervals indefinitely.

Observation of some long-term elderly guests who favored low-g suites led to research that showed slowing of the aging process and cessation of the progression of Alzheimer's disease in low-g environments. As a result, Rockdonnell established Sun-Up City in 2028, a retirement community that offers low-g residences and a slightly oxygen-enriched atmosphere to promote longevity and health.

Rockdonnell sees the "Argonom" Space Settlement contract as a logical extension of its successful work with the Foundation Society.

## VEREINIGTEN FLUGFAHRTEN GmbH

Located in Munich, Vereinigten Flugfahrten is a major aircraft builder, and the European Community's largest spacecraft manufacturer. The company also uses its excellent metals fabrication facilities for subcontracts in other product lines; it has manufactured door panels for the European model of Ford vans, housings for household electrical appliances and commercial test instrumentation, and components for high-speed trains.

The company entered the spacecraft market in the 1970's; its products have included satellites for a wide variety of applications, upper stages for satellites launched by Ariane launch vehicles, and subassemblies for the Ariane rockets themselves. In the early 2000's, the European Community opted to fund production of a vehicle derived from Vereinigten Flugfahrten's Sanger Spaceplane design. Sanger successfully met design objectives, although its small payload capacity (1500 lb. to Low Earth Orbit) restricted its commercial value. Experience with Sanger in hypersonic flight did, however, lead Vereinigten Flugfahrten to develop by 2009 commercial aircraft that cruise at Mach 5, which beat the American entry into this market by three years. In 2021, the company replaced Sanger with Weltraumreiseflugschiff, which entered service by providing charter flights for commercial space operators and for the European and Japanese tourist markets. To compete with other SSTO manufacturers, the company now offers a family of launch vehicles with payload capabilities to 80,000 lb.

The company's major launch vehicle customer is European Space Lines, which provides passenger service to orbiting hotels that cater to guests from Europe, Africa, and developing countries. Vereinigten Flugfahrten and ESL entered into a partnership in 2028, in order to develop the South Saharan launch site. Vereinigten Flugfahrten provided technical support and construction management to assure that passenger terminals, cargo loading equipment, and maintenance facilities would be completely compatible with all models of the Weltraumreiseflugschiffen. European Space Lines manages the launch site and operates all passenger and cargo handling services, including scheduling and service agreements with conventional ground transportation services and airlines that deliver passengers and cargo for transfer to launch vehicles. Vereinigten Flugfahrten provides maintenance and repair of the launch vehicles, which are owned by ESL.

Vereinigten Flugfahrten has a tradition of success that relies on self-sufficiency within the corporation. Because of this, it is involved in making many products that most spacecraft manufacturers would acquire through subcontracts. One of the consequences of this policy was the company's own development of computers and cockpit displays installed in its launch vehicles. An internal "Synergy Department" adapted some of the vehicle computer technology to develop new computer systems for use in office areas, whereupon the Marketing Department recognized a commercial product opportunity. As a result, a Vereinigten Flugfahrten subsidiary surprised the global computer industry in 2024 when it introduced computers built into office desks, with a screen occupying the entire desk top. Touch-screen control of files enables handling computer files like papers on a desk, with many documents visible and "shuffeable" simultaneously. It took computer companies almost a year to introduce competing products, by which time Vereinigten Flugfahrten had established itself as one of the world's leading computer makers for the retail market.

Vereinigten Flugfahrten also built European modules for the International Space Stations and lunar bases. By including some company-owned materials processing experiments in these modules; the company developed extensive expertise in producing a wide variety of products in microgravity, and in extracting useful materials from lunar ores. The company is known to use some products from these ventures in its satellite projects, and a few very high-quality optical products and electrical components have been sold to selected customers. The company surprised the world-wide retail optical products market with its introduction in 2015 of "soft glass", which enables space-manufactured contact lenses to offer the comfort of soft lenses with the easy care and optical clarity of hard lenses. In order to assure complete privacy in its development of space-manufactured products, Vereinigten Flugfahrten established its own orbital manufacturing and research facility in 2023.

Always on the prowl for new markets, and fearless about challenging established industry leaders at their own games, Vereinigten Flugfahrten sees the "Argonom" contract as a prime opportunity for developing a new customer base and business area--and to gain access to the unlimited resources of Mars.

## VULTURE AVIATION

Corporate Headquarters are located in Issaquah, Washington, with manufacturing facilities primarily scattered around Washington State's Puget Sound area. Vulture Aviation is the world's largest aircraft manufacturer, having built 70% of the commercial jet, propfan, and supersonic aircraft operating in the world.

New (and proprietary) techniques invented by the company to increase airframe service life led to saturation of markets for new aircraft about 15 years ago. Company revenues due to aircraft sales have been stagnant since nearly all major airlines completed adding the new-technology aircraft to their fleets. When Vulture Aviation recognized 20 years ago that this trend was starting, its executives resolved to diversify their business, and become a full-service aerospace company. This was accomplished with the purchase of Consolidated Dynamics, a respected but poorly managed manufacturer of satellites and orbital transfer vehicles, in 2034. The strategy paid off; the expanded Vulture Aviation won the Foundation Society's contract to build Aresam.

Under Vulture Aviation's ownership, the old Consolidated Dynamics divisions improved their traditional products, but also adapted them; Aresam and the Foundation Society's interest in Mars provided opportunities to develop entire constellations of communications, navigation, and observation satellites in orbits around Mars. In order to provide transportation to Aresam, Vulture Aviation built four large "cyclor" spacecraft, which are in elliptical solar orbits that cross the orbits of Earth and Mars when the planets are relatively close by. Transfer ships rendezvous with the cyclor spacecraft to load and offload cargo and personnel. These ships remain the only means of transportation between Earth orbit and Mars.

Several wholly-owned subsidiaries provide missile range operation and maintenance for the U.S. Air Force and European Community Air Defense Command, fishing equipment, and energy conversion systems. Projects in the latter business area include energy production from swamp vegetation, solid waste products, tidal action, and windmills. A research division stunned the scientific community last year by successfully generating and containing small black holes; a variety of commercial uses of this technology is being investigated, so far inconclusively.

Outside of the aircraft business, Vulture Aviation is most well-known for its single-stage-to-orbit manned launch vehicle, the Condor. In 2008, when it became clear that the Rockonetics Mach 25 engine was reliable enough to support commercial operations, the company committed to development of a vehicle with 25,000 lbs. payload capability to LEO. Customized versions entering service beginning in 2013 assured profitability for fledgling earth orbiting manufacturing and commerce facilities. Condor offered launch services at \$550 per pound, with discounts to \$500 per pound for multiple flight bookings. Cargo is installed in a shorter version of the standard cargo containers, 30 feet long with the same 15-foot cross-section. Vulture is protecting the innovations involved in production of Condor by refusing to sell any units; the growing fleet is owned and operated by the company's SpaceFreight Division, which operates scheduled cargo and passenger service to major earth-orbit facilities, including the Foundation Society's orbiting space settlements. Service to smaller facilities is arranged on a charter basis. The company now offers a family of Condor vehicles, with up to 40,000 lbs. payload capability to LEO, and launch rates as low as \$400 per pound for preferred customers. Wingless versions built on-orbit at Bellevistat (through a cooperative agreement with the Foundation Society) provide service from orbital facilities to the lunar surface and other space destinations.

Given Vulture Aviation's unique experience with large-scale operations in the vicinity of Mars, the company's executives are confident of winning the Foundation Society's "Argonom" contract.

# REQUEST FOR PROPOSAL

11 October 2047

## "Argonom" Space Settlement Contract

### INTRODUCTION

This is a request by the Foundation Society for contractors to propose the design, development, construction, and operations planning of a Space Settlement Community on the surface of the planet Mars.

The need and requirements for the "Argonom" Space Settlement have been established through studies performed by the Foundation Society, and through experience gained during development and operations of our existing Space Settlement Communities.

### STATEMENT OF WORK

1. **Basic Requirements** - The contractor shall describe the design, development, and construction of the "Argonom" Space Settlement Community, and develop plans for operations and support required to maintain the community. The Society wishes to minimize operating costs as much as practicable. Anticipated problem areas and/or requirements for advancements in state-of-the-art technology must be identified in the proposal, with options for resolution.
2. **Facilities** - Argonom must accommodate a community of 12,500 full-time residents plus an additional transient population, not to exceed 600 at any time, of business and official visitors, guests of residents, and vacationers; some of the visitors will be scientists studying Mars, its environment, the effects of large-scale human habitation on that environment, and ecosystem(s) (if any). The design must enable use of natural light, and views of surrounding terrain.
  - 2.1 Exterior design drawings must identify utilization of all volumes, must illustrate the local terrain and compatibility with it, and must clearly show dimensions of major structural components. The proposal must identify construction materials utilized for major structural components. The design and materials must be capable of retaining their functionality and appearance in the Martian environment, without requiring significant expenditures of settlement resources for maintenance and repair. The proposal shall specify safety considerations and system redundancies, including protection from radiation and debris penetration. It is expected that drawings of the exterior will at least include identification of locations for landing site(s), vehicle maintenance facilities and parking areas, cargo and resources storage and/or warehousing, public utilities, heavy industry, residential/commercial areas, and agriculture.
  - 2.2 The Argonom design must specify utilization of interior space, with areas designated and drawings clearly labelled to show industrial, residential, commercial, agricultural, and other uses. The proposal must provide justifications for facility sizes and locations. At least one drawing must show the total interior area of the settlement, and the proposal must include maps to show utilization of all interior areas; such drawings must clearly show dimensions of areas designated for specific uses. Research areas must include a laboratory for study of Mars samples that may contain evidence of life, and must be quarantined for protection of Argonom's population.
3. **Operations** - The contractor shall describe provisions for all operations necessary to support the community, including conduct of businesses for external trade and accommodating incoming and outgoing vehicles--including spacecraft, surface vehicles, and aircraft.
  - 3.1 The proposal shall identify a recommended location on the Martian surface, and the reasons for its selection. Explain how searches for evidence of life on Mars could be conducted from this location. The proposal shall identify the sources of materials and equipment that will be used in construction and operations--Earth, asteroids, existing on-orbit facilities, Earth's moon, Mars

itself, or elsewhere--and means and costs for transporting those materials to the Argonom location. The proposal should describe the process required to construct the settlement, by showing the sequence in which major structural components will be assembled. The proposal should detail any special construction techniques or automation required to complete the settlement.

3.2 The proposed Argonom design shall include elements of basic infrastructure required to support the activities of the settlement's residents, including (but not limited to):

- food production,
- electrical power generation,
- internal and external communication systems,
- internal and Martian surface transportation systems,
- water management,
- household and industrial solid waste management,
- atmosphere/climate/weather control, and
- day/night cycle provisions.

The proposal must define transportation corridors and means of access throughout and between facilities, including designs of transportation vehicles proposed for use in and around the settlement. Drawings of facilities related to transportation systems must show their dimensions, either as the size of the "footprint" they occupy on a map, or their length/width/height. Operations planning must consider that supply lines for imports may be interrupted for up to six months.

3.3 The proposal must describe any existing or new on-orbit infrastructure required to sustain settlement operations (e.g., vehicles, satellite support, power plants, or other permanent installations). It is preferred that these requirements be shown in a chart or table. The Foundation Society does not intend to fund development of new vehicle(s) for transporting goods and personnel to the Martian surface, and/or for transporting construction materials from extraterrestrial/extramartian sources. The proposal shall, however, identify requirements for any new launch/landing, on-orbit, or Mars surface vehicles that will be needed during construction, occupation, and operations of Argonom, so that the Foundation Society can encourage commercial development of these vehicles.

4. **Human Factors** - Quality of life is an especially important consideration for Foundation Society members, who plan to maintain traditional comforts of Earth without the sacrifices normally associated with a frontier environment. Argonom must provide a safe and pleasant living and working environment for residents of its community(ies). Please bear in mind the traditional human factors that a wealthy resident of one of Earth's major cities might enjoy (e.g., large houses, fine food, access to world-class entertainment). Consider also that humans prefer natural sunlight, and part of the appeal of living on and visiting Mars is what can be seen there.

4.1 Argonom communities shall provide their residents with facilities for customary services (e.g., housing, education, entertainment, medical, parks and recreation, etc.), variety and quantity of consumables and other supplies, and public areas designed with open space and consideration of psychological factors. The proposal must depict or specify means of distributing consumables to Argonom residents. The proposal shall include maps and/or illustrations depicting community design and locations of amenities, with a distance scale. Medical facilities must be available for quarantine and treatment, if necessary, of people who may become exposed to Martian life forms.

4.2 The proposal shall include designs of typical residential accommodations, clearly showing room sizes. The full-time inhabitants will be Foundation Society members who are involved with development of facilities for further habitation of Mars, who operate business ventures in the settlement or elsewhere on Mars, who manage settlement maintenance and operations, and who produce products and services as needed by the community and for trade. Anticipated demographics of the original population are:

Married adults	67%
Single Men	14%
Single Women	11%
Children	8%

4.3 The proposal shall specify systems, devices, vehicles, and design characteristics as required to enhance productivity in the Mars environment (both inside and outside the settlement). Drawings of these items must clearly indicate their sizes.



5. **Automation** - Contractors' proposals must specify number and types of computers, software, network planning, and robotics applications required to support Argonom's facility and community operations. Show robot designs, clearly indicating their dimensions. Identify locations and sizes of support facilities and special transportation corridors for robots. Provide a chart that identifies all anticipated computer and robotics requirements in and around the settlement, and identifies the particular computers and robots that will meet each automation need.

5.1 Specify automation systems to sustain integrity of the settlement environment and infrastructure, including backup systems and contingency plans for failures. The proposal must define physical locations of computers and robots that support critical functions. Emphasize automation support to construction, development of infrastructure on Mars, maintenance, repair, and safety systems. Robots that operate outdoors must be capable of retaining their functionality and appearance in the Martian environment.

5.2 Specify automation systems to enhance livability in the community, productivity in work environments, and convenience in residences. Emphasize automation support to commercial, agriculture, and port operation activities. Use of automation to reduce requirements for manual labor is a high priority for the Foundation Society.

5.3 Robot systems required for emergency external repairs must be capable of accomplishing tasks and surviving during solar flare activity.

6. **Schedule and Cost** - The proposal shall include a schedule for development and occupation of Argonom, and costs for design through construction phases of the schedule.

6.1 The schedule must describe contractor tasks from the time of contract award (12 October 2047) until the customer assumes responsibility for operations of the completed settlement. Show in the schedule the dates when Foundation Society members may begin moving into their new homes, and when the entire original population will be established in the community.

6.2 Specify the costs associated with Argonom design through construction in U.S. dollars, without consideration for economic inflation.

6.2.1 Include estimates of numbers of employees associated with each phase of design and construction in the justification for contract costs to design and build Argonom. Show separate costs associated with the different phases of construction.

6.2.2 Describe costs that the Foundation Society will be expected to incur annually to operate the settlement, including:

- personnel,
- maintenance,
- supplies, and
- services;

these costs will not, however, be included in the Argonom contract.

7. **Business Development** - Argonom must be designed to accommodate a variety of commercial and industrial ventures. The settlement must include adequate provisions for commercial activities to enable economic self-sufficiency for on-going operations five years after initial full occupancy and operational capabilities are achieved. Trade will be conducted with Earth and other space facilities. The basic design must include sufficient flexibility to accommodate development of additional compatible business types with little configuration change. The original configuration must, however, accommodate three major business pursuits:

- Infrastructure Development
  - Argonom will serve as a staging area and headquarters for construction of roads and other facilities to service expanding operations on Mars
  - Long-distance surveying expeditions will be provisioned and serviced at Argonom
  - Construction crews, their equipment, and supplies will be routed through Argonom
- Mining Operations
  - Ores from potential mining sites will be assayed to determine commercial value
  - Mars materials will be extracted and prepared for transportation to users
  - Customers may require refining and/or separation of materials before delivery
  - Customers may request delivery of manufactured parts

- Hotel
    - Lodging and related facilities are required for up to 500 guests
    - Up to half of hotel guests are expected to be tourists
    - Proposals shall recommend anticipated numbers, demographics, stay times, and itineraries of tourists
    - Hotel facilities must be readily expandable if justified by customer demand
8. **Special Studies** - Plans shall be included in the proposal for emergency procedures to react to two disaster scenarios:
- Damage to an inhabited part of the facility due to meteorite or debris penetration, or collision by a vessel, including a 1.5 meter diameter hole that allows contained atmosphere to escape
    - Describe safing plan to isolate affected volume from other parts of the settlement
    - Describe provisions to maintain structural integrity during loss of atmosphere
    - Provide a schedule of tasks necessary to accomplish repair activities and resumption of full service in affected volume
  - Contamination of atmosphere in connected habitable areas due to explosion involving hazardous chemicals
    - Describe provisions for relocation of affected personnel and activities during clean-up
    - Schedule activities to return the settlement to full operation

### **ADDENDA**

Submitted proposals may suggest alternate names for this community, within the Foundation Society's established naming convention that requires the name to begin with the letter "A" and end with the suffix "om".

The proposal may suggest an alternate population for the settlement, if warranted to assure fulfillment of Argonom business objectives and maintenance requirements.

If a proposal is submitted that has more than the allowed 50 pages, only the first 50 pages will be provided to the judges.

Drawings and/or maps included in the proposal must show dimensions consistently in English (feet/miles) or metric (meters/kilometers) notation.

# **PRELIMINARY**

## **REQUEST FOR PROPOSAL**

**10 October 2047**

### **"Argonom" Space Settlement Contract**

#### **INTRODUCTION**

This is a request by the Foundation Society for contractors to propose the design, development, construction, and operations planning of a Space Settlement Community on the surface of the planet Mars.

#### **STATEMENT OF WORK**

1. **Basic Requirements** - The contractor shall describe the design, development, and construction of the "Argonom" Space Settlement Community, and develop plans for operations and support required to maintain the community.
2. **Facilities** - Argonom must accommodate a community of 12,500 full-time residents plus an additional transient population, not to exceed 600 at any time, of business and official visitors, guests of residents, and vacationers; some of the visitors will be scientists studying Mars, its environment, and ecosystem(s) (if any). Exterior design drawings must clearly show dimensions of major structural components. The Argonom design must specify utilization of interior space; drawings must clearly show dimensions of areas designated for specific uses.
3. **Operations** - The proposal shall identify a recommended location on the Martian surface, and the reasons for its selection. Explain how searches for evidence of life on Mars could be conducted from this location. The proposed Argonom design shall include elements of basic infrastructure required to support the activities of the settlement's residents, including food production, electrical power generation, communication systems, transportation systems, water management, household and industrial solid waste management, atmosphere/climate/weather control, and day/night cycle provisions.
4. **Human Factors** - Argonom communities shall provide their residents with facilities for customary services (e.g., housing, education, entertainment, medical, parks and recreation, etc.), variety and quantity of consumables and other supplies, and public areas designed with open space and consideration of psychological factors. The proposal shall include designs of typical residential accommodations, clearly showing room sizes.
5. **Automation** - Contractors' proposals must specify number and types of computers, software, network planning, and robotics applications required to support Argonom's facility and community operations. Show robot designs, clearly indicating their dimensions. Specify automation systems to sustain integrity of the settlement environment and infrastructure, including backup systems and contingency plans for failures. Specify automation systems to enhance livability in the community, productivity in work environments, and convenience in residences.
6. **Schedule and Cost** - The proposal shall include a schedule for development and occupation of Argonom, and costs for design through construction phases of the schedule.
7. **Business Development** - Argonom must be designed to accommodate a variety of commercial and industrial ventures. The original configuration must, however, accommodate three major business pursuits: Infrastructure Development, Mining Operations, and a Hotel.

## Appendix A: SUBCONTRACTORS

Major aerospace contractors and customers have access to a vast network of non-aerospace and smaller companies with relatively limited product lines. They are eager to make or do anything they are capable of making or doing, for anyone who will pay. They frequently have contracts with competitors for the same proposal. These include:

**BeamBuilders, Ltd.** is a European company which operates an automated manufacturing facility on a ferro-nickel asteroid that it has placed in orbit around the Earth-Sun L4 libration point. The company produces triangular trusses to customer-specified dimensions, at the rate of 600 linear feet per hour. Customers are required to provide their own transportation of these structures, although some limited assembly is permitted in the vicinity of this operation. The company's standard triangular truss with 12-foot sections, suitable for zero-g installations, typically sells for \$1000 per linear foot. Custom orders are more expensive.

**Efficient Software, Inc.** was founded by four Bellevistat engineers who recognized that people making their homes in space have some incentives for not wanting to constantly expand their computer systems to accommodate increasingly complex and memory-hogging software. The company is licensed by major software producers to convert popular new programs into more-efficient versions that are compatible with files prepared using the original software, but require less memory, bandwidth, and other resources. The company's products have also become popular among some segments of the dirtside public. Efficient Software avoids a quagmire of lawsuits by paying licensing fees to the original software suppliers.

**Fusion Founders** serendipitously happened upon an apparently ideal combination of conditions and equipment to produce practical fusion power in 2013. The company has been busily producing power plants since that time, at its manufacturing facility in Yukon Territory. Although it can assemble large municipal power plants at customer-specified sites, its most popular product is a self-contained unit that can be shipped on a modified commercial version of a C-19 transport aircraft, and installed by local labor with supervision provided by a company engineer. The unit, weighing 200,000 pounds, includes a 17-foot diameter sphere, its 80-foot-long cooling "barn", and a support "shed". The system is shipped pre-assembled, and generates 10 MW, appropriate for non-industrial communities of about 5000 people. Fusion Founders has received several solicitations to develop a version of this unit that could be launched into space, but feels that it has achieved the theoretical limit of smallness for a fusion reactor. The company has offered to attempt to develop such a reactor if it is paid a \$10 billion fee, but will not guarantee success.

**Heavenly Jitneys** provides regular but unscheduled transportation services between locations in Earth orbit, including all space stations, settlements, and major commercial sites. The service was started by a pair of Alexandriat residents using vehicles built at Bellevistat for the company's fleet, which is based at Columbiat. Although primarily a service for passengers and their luggage, the company can haul some cargo either in small packages that fit in the passenger compartments, or secured to a 10 by 15 foot flat surface on the "bottom" of each vehicle. Rates average \$10,000 per person per day of travel, and \$50 per pound of cargo per day of travel.

**Litigation Limiters** is a law firm that founded a niche market which virtually eliminates conflict-of-interest suits for its clients, who usually are companies competing for the same contracts but in need of each others' products and/or services. Litigation Limiters arranges its own contracts between providers of products and services, and customers, then serves as a go-between to supply the products and services to the customers. The company has such agreements with all of the world's diversified corporations that have significant product lines applicable to space development. Litigation Limiters charges a 2% fee on product or service value.

**Lossless Airlocks** is a Bellevistat manufacturer that has developed and sells airlocks that operate with almost no loss of atmosphere for each opening to space. Airlocks come in several sizes, including a single-person unit, and a personnel transfer system that can simultaneously

accommodate ten people in adjacent chambers; the largest is an equipment transfer chamber designed for standard space cargo containers (15 feet square by 45 feet long). The system is somewhat disconcerting for people to use; when outgoing, a coated kevlar tube envelops the occupant, who is then ejected rather forcefully when the outer doors are opened. It has, however, enabled retention of precious air in all sizes of vehicles, and is an important asset for preservation of the fragile indigenous lunar atmosphere. In response to some serious problems with soil contamination of machinery in lunar bases, the company has been attempting to develop an airlock that will clean astronauts' suits as they enter controlled environments; the fine-grained, sharp-edged, electrostatically-charged lunar dust has, however, resisted all attempts to control it.

**Lunar Adventures** is an Alaskol-based operation that provides spacesuits and guide-operated vehicles for excursions on the lunar surface. The vehicles provide a shirtsleeve environment for six passengers plus the guide, and accommodations for overnight "camping". The electric-powered vehicles can be self-sufficient for up to a week in sunlight with storage for two days of power in darkness, and have a range of 200 miles per day. Passengers are charged \$1000 per person per day, or \$5000 per day for charter of a vehicle and guide. Spacesuit rentals are \$150 per day.

**OrbitLink Communications** was established when the Alexandriat Space Settlement was under construction, to augment standard communications channels. Individuals who insist on transmitting and receiving data-hogging video and interactive real-time data with Earth-based services do so by paying exorbitant fees to OrbitLink. The company has made arrangements to place one of its antennas and dedicated fiber optics links on every Foundation Society settlement.

**Tanks-A-Million** is a Belvestat-based manufacturer that uses lunar materials to build tanks for all applications on spacecraft. The company has facilities that can make nearly perfectly round tank cross-sections to any size between one foot diameter spheres and 18 foot diameter by 50 foot long cylinders. Tanks can be specified for high pressure, cryogenic, or fuel applications, and feature an extraordinarily reliable system for keeping contents at the exit points in zero g. The company claims that its zero-g manufacturing techniques reduce flaws and "corners" that can serve as starting points for stress fractures in pressurized tanks.

**Totally Remote Ultimate Escapeways / Guest Requested Innerpeace Treks (TRUE/GRIT)** offers the ultimate get-away-from-it-all vacation. Guests enjoy luxuriously-appointed small spacecraft which can accommodate up to four people for two weeks. The company delivers each spacecraft and its guest(s) to an orbit with no hazards from known debris, where it remains either until its occupants request retrieval or supplies are nearly depleted. Privacy is guaranteed, although critical vehicle systems, oxygen depletion, and temperature are monitored to assure that occupants are not in difficulty. Guests may change the attitude of the vehicle for different views, but have no ability to change orbits. Rates are \$9000 per person per day, or \$30,000 per day for charter of a spacecraft. Extravehicular Activity (EVA) experiences are offered for \$1000 extra per person per trip. These zero-g escapes are highly favored by designers, authors, and artists who seek creative inspiration.

**ZAP! Industries** is the leading supplier of wire harnesses and fiber optics systems for distribution of electrical power and electronic signals on spacecraft. In 2025, the company completed development of a system for zero-g manufacturing of solar cells from materials available in silicate asteroids. ZAP! sells each of these units for \$40 million, not including transportation to deposit it on an appropriate asteroid, where it produces 1 x 2 foot solar panels at the rate of 10,000 per day, each of which is capable of generating 40 watts of power in Earth orbit and weighs 2 pounds, at a cost of \$40 per kW (not including transportation to the use site).

## Appendix B: Space Settlement Design Competition GLOSSARY

Many of the words and terms used in Space Settlement Design Competitions materials are not part of familiar everyday usage:

**air-breathing engine:** a propulsion plant (motor) that acquires oxidizer from the air, rather than carrying it in tanks on the vehicle (as required by rocket engines)

**airlock:** a chamber that enables people and things to move or be moved between volumes with different pressures; like a lock in a canal, the chamber starts at the pressure that the occupant is moving from, and changes to the pressure being moved to

**attitude (of a vehicle):** a vehicle's orientation relative to Earth, Sun, or other objects; typically used to describe a desired view, observation target, or heating environment (e.g., a "sun-facing" attitude assures that one side of the vehicle will always be hot, and the other side always cool)

**avionics:** literally, "aviation electronics", mostly including commanding and monitoring of systems on aircraft and spacecraft

**cargo:** the reason a vehicle flies; stuff that is carried by a vehicle from its starting point (ground or on-orbit) to the vehicle's destination; can include satellites, bulk materials, construction components, or people

**cargo container:** a standard carrier in which cargo is carried for a mission; ideally, all spacecraft cargo is containerized, because complex installations and interfaces can be accomplished to the inside of the container, and the standardized exterior interfaces of the container can be quickly mated to the inside of a cargo vehicle (standardized containers have been used for decades on ships, conventional aircraft, railroad cars, and trucks)

**consumables:** stuff that is used up during the course of a mission or over a period of time, and hence must be replaced; includes everything from rocket fuel to pet food to pencils

**contract:** a legal agreement between a customer and a company (contractor), whereby the contractor agrees build something or provide a service within a defined cost and schedule, and the customer agrees to pay the cost when the product is delivered (contracts may have provisions for partial payments over the course of a long product delivery schedule)

**dirtside:** of or referring to Earth, people living there, and things on it

**down area:** in a rotating space structure, the interior surfaces through which the force due to the rotation ("artificial gravity") appears to be vertical; conversely, surfaces inside a rotating space structure on which a person could stand or things could be placed, as if they were on the ground

**Expendable Launch Vehicle (ELV):** a launch vehicle which is used for only one launch; typically, it sheds some of its components, or stages, during the launch process, with only a small portion of the original "stack" being delivered all the way to orbit

**Extravehicular Activity (EVA):** an excursion by a person in a spacesuit outside of any vehicle or habitat

**fabrication:** manufacture; the process of making, building, and/or assembling

**GEO:** geosynchronous Earth orbit; objects in 22,300 mile orbits rotate around the Earth at the same rate that the Earth turns on its axis; when located above the Equator, these objects appear to be stationary in Earth's sky

**fiber optics:** use of tiny, transparent strands to transmit light that represents electronic signals; can replace traditional copper wire with less weight and expense, and greater reliability, but is not capable of transmitting power

**hypersonic flight:** flight through an atmosphere at greater than five times the speed of sound (Mach 5) for that atmosphere

**Lagrangian points:** (see "libration points")

**launch vehicle:** a spacecraft that is capable of launching or flying through an atmosphere (e.g., Earth's) in order to get into space and achieve orbit

**LEO:** low Earth orbit; orbital locations above Earth's atmosphere and below the Van Allen radiation belts

**libration points:** in orbital mechanics, when one large body (e.g., the Moon) is in orbit around another large body (e.g., Earth), there are five points in orbits around the larger body where gravitational forces balance out to enable satellites to be placed where they could not stay if the smaller of the large bodies were not present (also called Lagrangian points, for Joseph Lagrange, the mathematician who developed the theory that predicts their existence)

**low-g:** acceleration environment with less than the acceleration due to gravity on Earth's surface

**mass driver:** a device that electromagnetically accelerates small objects to very high velocities; can be utilized for efficiently launching material from airless surfaces

**micro-g:** an accurate description of "weightlessness", the condition experienced in space when forces balance out and objects seem to "float"; true "zero-g" is theoretically not possible, because there are always some tiny forces operating on all objects

**on-orbit:** in space, in an orbit; usually refers to an orbit around Earth

**orbit:** the path assumed by an object in space, due to balancing or "cancelling out" of accelerations due to gravity and rotation; usually the elliptical path of a small body (e.g., satellite) around a very large body (e.g., planet, moon, or star)

**overhead:** the part of a budget that does not show up as part of the cost of work directly on a project, but is charged to the customer as part of the hourly charge for direct work (i.e., a contractor is paid for each hour an engineer works on tasks directly related to the project; the customer is billed a cost for the engineer's hours that is greater than the salary paid to the engineer; the difference pays for computers, upkeep of the facility, janitors, utilities, secretaries, and other costs required to support the engineer's work)

**payload:** literally, "paying load"; cargo carried by a vehicle, for which a fee is being paid in exchange for moving the cargo to its destination

**payload capability:** weight of payload(s) that a launch vehicle is capable of carrying to orbit

**payload integration:** the process of safely stowing a payload (usually a satellite or complex device) on a launch vehicle and providing services (often including electrical power, avionics, and thermal control) that enable the payload to survive the flight and accomplish its purpose; includes design of payload services, analysis of payload's ability to survive environments it will experience, and installation in the vehicle

**profit:** the difference between the price charged by a contractor for providing a product, and the actual cost the contractor incurs to make the product

**proposal:** a document prepared by a company or other entity, in order to convince a customer to select the company as the contractor that will provide a certain product; it describes the company's recommendation for how it could provide the product, and explains why the customer should have confidence that the company has a superior design and can be relied upon to produce it according to the customer's requirements and within the described cost and schedule

**Request for Proposal (RFP):** a document prepared by a customer, which describes features of a product they want a contractor to produce

**requirements:** features that a customer requests to be included in the design of a desired product

**Reusable Launch Vehicle (RLV):** a launch vehicle that returns from its missions intact, and is designed to be maintained after flight and fly repeated missions

**satellite:** any object in orbit around another object; usually refers to human-made devices in orbit around large natural bodies (i.e., planets, moons, stars)

**shirtsleeve:** an environment inside a vehicle or habitat that enables humans to operate without protective clothing

**Single Stage to Orbit (SSTO):** the capability of a launch vehicle to accomplish a mission from the ground to orbit without staging, or shedding of components during the launch process; such vehicles contain all of the fuels and oxidizer they require in tanks inside their structures, and return to the ground with the tanks intact (the amount of oxidizer required can be reduced through use of air-breathing engines during flight in the atmosphere)

**solar panel:** a device that converts sunlight into electrical power

**Solar Power Satellite:** a satellite, usually very large, consisting mostly of large arrays of solar panels producing electrical power that can be converted (usually to microwave energy) and transmitted to users in other locations

**solar sail:** a surface, usually very large and lightweight, that makes use of pressure due to light or solar wind for propulsion

**spacer:** of or referring to people who live in space

**spacesuit:** a garment that provides pressure, breathing air, fluids and nutrients, waste removal, and protection against the space environment, and that enables a human to move and operate in the space environment

**SSTO:** see "Single Stage to Orbit"

**Van Allen radiation belts:** bands of radiation trapped in Earth's magnetic field, which both absorb ambient deep-space radiation and provide protection for Earth's surface, and are a hazard for satellites and humans operating within them

**zero-g:** see "micro-g"



# **Antelope Valley Space Settlement Design Competition**

## **SCHEDULE OF EVENTS**

**October 10 - 12, 1997**

### **Friday 10 October**

5:00 p.m.	Registration and check-in at Antelope Valley High School
6:15 p.m.	Buses leave for NASA - Dryden Flight Research Center
7:15 p.m.	NASA-Dryden Flight Research Center Program and Tour
9:15 p.m.	History of Space Settlements
9:30 p.m.	You're in the Future Now! – What Will Happen to You this Weekend
9:45 p.m.	How Companies Work
10:00 p.m.	You're a Professional Now!
10:10 p.m.	Assignments to Design Competition Companies
10:30 p.m.	Buses return to Antelope Valley High School
12:00 midnt	Lights out! in gymnasium sleeping quarters

### **Saturday 11 October**

8:00 a.m.	Breakfast and Teams meet with CEO's
9:00 a.m.	Technical Training Sessions
10:30 a.m.	Teams meet in Company Headquarters to Begin Preparation of Designs
12:00 noon	Lunch
6:00 p.m.	Dinner
11:00 p.m.	Library closes
12:00 midnt	Lights out! in gymnasium sleeping quarters

### **Sunday 13 October**

7:30 a.m.	Companies submit finished Design Proposals to Foundation Society
7:30 a.m.	Breakfast
8:30 a.m.	Assemble for Design Presentations
8:40 a.m.	First Presentation
9:30 a.m.	Second Presentation
10:20 a.m.	Third Presentation
11:10 a.m.	Fourth Presentation
12:00 noon	Lunch
1:00 p.m.	Activity during Judges' deliberation
3:00 p.m.	Judges' debriefing
3:30 p.m.	Announcement of Winning Design
4:00 p.m.	Adjourn



# VICTOR VALLEY

## CAROL C. LINDVALL DESIGN COMPETITION



NOVEMBER 14-16, 1997





# Space Settlement Design Competition

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## Acknowledgements

The Space Settlement Design Competition was made possible by donations of funding, materials, services, and time by several organizations, companies, and individuals. The following have earned special recognition for their generosity:

### **COMPETITION ORGANIZERS**

**Dick Edwards**

Boeing Reusable Space Systems; Downey, California

**Anita Gale**

Boeing Reusable Space Systems; Downey, California

### **SPONSORS**

**NASA - Dryden Flight Research Center**

With special thanks to Lee Duke and Marianne McCarthy

**Victor Valley College**

With special thanks to Kathleen Moore

**Apple Valley Science and Technology Center**

With special thanks to Rick Percy

**American Institute of Aeronautics and Astronautics Orange County Section**

### **DONORS**

**Keebler Foods**

With Special Thanks to Debby Roy

**Ron's Mobile Disk Jockey Service**

### **SUPPORTERS**

**Boeing North American**

With special thanks to Tom Kennedy and Bob Tucker

**American Institute of Aeronautics and Astronautics Antelope Valley Section**

With special thanks to Alan Sutton



# Space Settlement Design Competition

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## Acknowledgements

It would not be possible to conduct the Space Settlement Design Competition without the selfless contributions of volunteers. The Competition organizers and sponsors sincerely appreciate the efforts of the following individuals:

### **CHIEF EXECUTIVE OFFICERS**

Capt. Michael Lindauer  
Edwards Air Force Base

Jack Spear  
NASA - Dryden

Lee Pitts  
Consultant

Brad Underhill  
Arthur D. Little Consultants

### **STRUCTURAL ENGINEERING TECHNICAL EXPERTS**

Laurie Barlow  
Architect

Nader Khalili  
Cal - Earth

### **OPERATIONS ENGINEERING TECHNICAL EXPERTS**

Dave File  
L'Garde

Nancy Wilson  
Consultant

### **HUMAN ENGINEERING TECHNICAL EXPERTS**

Gary Drylie  
U.S. Air Force, retired

Lauren Pomerantz  
California Space and Science Center

### **AUTOMATION ENGINEERING TECHNICAL EXPERTS**

Norm Avant  
Victor Valley College

Tom Quayle  
Consultant

### **TECHNICAL EXPERTS**

Eric Schmidt  
AIAA Antelope Valley Section

### **ADMINISTRATIVE SUPPORT**

Tom Quayle

## **Foundation Society to Build Settlement on Mars**

Foundation Society President Edwards Smith announced today that the organization's next space settlement--its seventh community in space--will be on Mars. Although it was confirmed that the settlement, tentatively designated "Argonom", will be on the Martian surface, a location was not specified. The Foundation Society seeks contractor advice for selecting settlement locations. This will be one of the Society's smaller settlements, with a population of only 12,500, but it is expected to be the first of many communities on Mars. The Foundation Society's decision was based on results of a planetary survey conducted by two dozen of its members over the past three (Earth) years. Mission leader Gale Uttamchandani and three team members returned recently to Foundation Society headquarters at Columbiat to report on their findings.

Uttamchandani said that the team typically travelled 50 km (30 miles) per day, and visited every major geological (areological, on Mars) formation on the planet. The team used three rovers with high ground clearance and eight wheels on independent axles. According to Engineer Tom Yubickovich, "the rovers worked really well. Sometimes one got stuck in some loose stuff or in rocks, but we could always use the others to pull it out of trouble." The rovers provided living quarters much like a recreational vehicle. Supplies were dropped by parachute every 90 days.

Members of the survey team are enthusiastic in their praise for Martian scenery. Areologist Peter Lee said "sometimes we came to the edge of an escarpment or rounded a corner in a valley, and we just had to stop to take it all in. Pictures don't do it justice. It was incredible: grand vistas, sweeping panoramas, stark and almost surreal."

The survey showed that resources on Mars are as widely distributed as on Earth, and the resources a community needs are not all in one place. Water is mostly in the north, in the polar cap and underground in higher latitudes. Surface material composition is almost uniform around

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-- more -- more -- more --



### Next Foundation Society Settlement on Mars

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the planet, owing to millenia of dust storms. The dirt has a variety of useful minerals in it, but not in commercially useful concentrations. Rocks are mostly unremarkable crater ejecta. Useful ore deposits are mostly in the southern highlands (exposed in deep crater walls), on the flanks of the Tharsis and Elysium volcanic regions, and exposed in canyons like Valles Marineris.

The team was perplexed in its search for evidence of life on Mars. As Uttamchandani said, "Mars is certainly not a place where little green men jump out from behind the rocks." Lee noted, however, that "some of the rocks we saw had details that just aren't explainable by normal lifeless processes. Sometimes it was a thin layer in a cliff that could once have been slime on a creek bottom. Sometimes it was a shape that might have been a solidified track or an impression from a plant. And these were always in the north, where there is more water." Smith said that a more dedicated search for Martian life will be an objective of Argonom residents.

The survey team is confident that Mars offers a wealth of opportunities for future habitation, although they did find one Martian attribute particularly vexing. Mineralogist Lisa Cantu said "the dust is so fine it's called 'fines'. It's not as abrasive as lunar dust, but it's worse at getting into things. Lunar dust gets kicked up and falls right down again. Martian dust hangs in the atmosphere a while. When the wind blows--even at hundreds of kilometers per hour--it's no problem keeping control of the rovers or even standing up outside, because the atmosphere is so thin. But the wind picks up the dust and it gets into everything, at any height. It stuck in the creases and weaves of our suits. It blew into our airlocks with us, and followed us everywhere. It defied every attempt to get rid of it. It reminded me of Colorado River silt in the Grand Canyon--after a week it was in our clothes, in our beds, in our food, everywhere."

Smith said that Argonom is named after the mythological ship Argo, which protected its crew through a series of adventures to far-off places as they fulfilled their quest for the Golden Fleece. "Mars is as remote and dangerous to us as Colchis was to Jason, and we need all the help we can get to make this a prosperous voyage for the Foundation Society."

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# Space Settlement Design Competitions

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## Victor Valley 1997

**Space Settlement Design Competitions** are industry simulation games for high school students, set in the future.

The Competitions emulate, as closely as possible, the experience of participating as part of an aerospace industry proposal team. This year's Space Settlement Design Competition participants will design a settlement on the surface of the planet Mars where over 10,000 people will make their homes.

To help them accomplish this challenging task, each team is provided with a manager from industry to act as Company CEO, and then team members are provided with technical and management training to prepare them for the Competition. They must design an overall structure, define sources of construction materials, specify vehicles used for transportation, determine sources of electrical power and water, design computer and robotics systems, specify allocation of interior space, show examples of pleasant community design, and provide estimated costs and schedules for completion of the project. The Competition concludes with the teams' presentations of briefings describing their designs to a panel of very critical judges.

The experience of participating in a Space Settlement Design Competition teaches young people optimism for the future, technical competence, management skills, knowledge of environments and resources in space, appreciation for the relationship between technical products and human use, ability to work in teams, and techniques for preparing effective documentation. It requires that students integrate their knowledge of and utilize skills in space science, physics, math, chemistry, environmental science, biology, computer science, writing, art, and common sense.

High schools in the Victor Valley and neighboring areas were invited to encourage their students to participate in this Competition. The event's primary sponsors are NASA - Dryden Flight Research Center and Victor Valley College .

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National Aeronautics and  
Space Administration  
**Dryden Flight Research Center**  
P.O. Box 273  
Edwards, CA 93523-0273



Reply to Attn of:

Welcome to the Second Victor Valley Space Settlement Design Competition. This competition is designed to challenge you creatively, provide an opportunity for collaborative learning, and to give you a taste of how scientists and engineers work in the real world.

NASA Dryden Flight Research Center is pleased to be sponsoring this event in conjunction with Victor Valley College, the Apple Valley Science and Technology Center, the American Institute of Aeronautics and Astronautics, and Boeing Reusable Space Systems Division. Special thanks are also due to Anita Gale and Dick Edwards of Boeing who designed and developed this competition.

This Space Settlement Design Competition represents just one of the many student programs that have been initiated since Dryden became a Center. However, this Design Competition is probably the most intense, grueling, and enjoyable of any of our education programs. I hope you have a good time, learn new skills, meet new friends, and, perhaps, begin to look at careers in science, mathematics, and engineering in a new way.

  
Kenneth J. Szalai  
Director

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SUPERINTENDENT  
PRESIDENT

*Nicholas L. Halisky*

Welcome to the second Victor Valley Space Settlement Design Competition! After an overwhelming success last year, it is indeed a pleasure for Victor Valley College to again host this competition. Reasoning, critical thinking, and application of knowledge are essential to student success—and this competition is an excellent opportunity to acquire and practice those application skills. I hope you have a valuable, energetic weekend.

Sincerely,

Nicholas L. Halisky  
Superintendent/President

—

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—

# ***GREETINGS AND SALUTATIONS!***

This is the year 2047.

You have been called to this meeting because your company is considering bidding on a contract to design and construct an ambitious project on the surface of the planet Mars. The agency that will award the contract is the FOUNDATION SOCIETY, an organization founded for the specific purpose of establishing settlements of its members in space.

**YOUR TASK** this weekend is to design facilities for a **SPACE SETTLEMENT** where thousands of people will live on the Martian surface. Your team must agree on a design that satisfies a set of requirements specified in the Request for Proposal (RFP) defined by the Foundation Society. You will prepare a **35 MINUTE** presentation describing your proposed design, which will be presented by one or more of your team members. The presentation must include dimensioned drawings of your design, and define areas designated for specific activities. You will be expected to justify facility sizes and locations, explain how the structure will be built and populated, estimate cost and schedule for construction, and show systems that will enable the residents to live and work in their new community. At the conclusion of your presentation, members of the Foundation Society will have the opportunity to ask questions about your design for 10 minutes. They will then evaluate your design versus those of your three competitors, and choose a winner.

Successful development of your proposal will require coordination of design details with engineers from four major disciplines in your company. Your company's management has the responsibility to assure that communication is both effective and timely, in order to assure that all of the RFP requirements are met, and that all parts of your design are compatible.

This is much to accomplish in a short time, so **GOOD LUCK!**

## HOW TO PLAY THE GAME

The Space Settlement Design Competition is an industry simulation game that both shows and requires use of corporate communication techniques to get the job done. Your disadvantage is that you have an inexperienced staff--but so do all of your competitors. Some basic skills you need to accomplish the task will be taught in your technical training sessions, and each training session will provide clues for solving a different part of the problem. The ONLY way you will get an effective design is for the people in all four of your engineering disciplines to communicate with each other. Every department influences the work of all the others. You must be cautious, however: if you carry communication to the limit, with everybody working on the same part of the problem all at once, you will be wasting time. You need to find a balance between doing the most things at once by having different people doing them, and having people working together to make sure the whole project fits together. Your CEO is a manager where he or she works, and does this all the time. Your President, Vice President of Engineering, and Department Directors will have to learn this quickly. Everybody in your company needs to focus on the common goal, which is to provide a unique design that meets the customer's requirements and is effectively communicated to the judges.

Assuming that you can get your team all working in the same direction, you will win this competition the same way any company wins a proposal competition: **BY SHOWING THAT YOU MEET THE CUSTOMER'S REQUIREMENTS**, and effectively demonstrating this in your presentation.

The managers of your company will receive from the Foundation Society a document, called the Request for Proposal (RFP), that describes EXACTLY what the customer wants your design to achieve. Your design should address every issue or point that the RFP includes. You will still have plenty of latitude for innovation in your design, because the customer wants you to figure out the details that will make it work best. But remember to meet ALL of the customer's requirements and show that you have done so in the proposal presentation.

You will do best if you also have a good presentation. It is said in industry that you can have the best design in the world, but it is worthless if you can't communicate it. This means that you should be thinking about your presentation and your briefing charts as soon as you start working on your design. Many companies hire whole departments of experts in "chartsmanship" who make sure that the company's designs are portrayed in the most effective manner. Your Vice President of Marketing and Sales is expected to perform this function. Make sure your presentation shows that your design meets every requirement in the RFP.

You also need to do your "homework". The judges will be very critical, and will be looking for weaknesses in your design. Be sure that you know more about it than you have put on the charts, and be sure that all of your presenters have a thorough knowledge of why the design is the way it is--and what it is. If one of your presenters calls something a solar dynamic power generator, and the next person calls it an antenna, the judges are likely to notice, and experience has shown that "on the spot engineering" usually only makes it worse.

Although innovation is encouraged, feasibility is essential. Any technologies assumed in your design which exceed those described in the competition materials must be justified (for example, if you plan to use warp drive in your proposal, explain how you plan to achieve it). The judges are engineers working in the aerospace industry, so base your design on reasonable interpretations of the level of existing technology defined by the competition organizers, the laws of Physics, and common sense.

The Competition organizers hope you have a good time in your attempt to win the favor of the judges. We hope you learn a lot, too, because we know that somewhere, right now--whether it be late at night or the middle of the weekend--there are people in industry doing exactly the same thing, but for real money and real jobs. You may join them someday, and this is a great opportunity to learn how the game is played.

GOOD LUCK!



## Just a Few RULES OF THE GAME

The Space Settlement Design Competition is to be conducted **ONLY** with materials and tools available at the Competition site, whether provided by Competition organizers or brought by the participants. No off-site assistance is permitted after participants arrive at the Competition host's facility.

You are working for a Company. Companies do all sorts of things besides creating products, and so can yours. Remember, however, that only a few people can make binding commitments for the company--and if you make a promise or commitment on behalf of your company without your CEO knowing about it, you may be fired. This applies especially to personnel decisions.

A small library of space related technical data will be maintained by the Foundation Society, with books available for one-half hour checkout. The library closes at 11:00 p.m. on Saturday, and all books must be returned by this time.

Food and drink items are allowed in your company headquarters, but you are expected to provide a janitorial staff that will maintain these facilities to professional standards. Companies that fail to maintain a clean and neat working environment (i.e., candy wrappers, uneaten food, stuff that fell on the floor, and trash in general must be deposited in proper waste containers) will be penalized.

Your Company's Proposal Presentation must meet the following requirements:

- Duration no more than 35 minutes (another 10 minutes allowed for judges' questions)
- Use viewgraphs (no more than 30 recommended; fewer preferred)
- Models and/or artwork are permitted
- Back-up viewgraphs may be used to assist in answering judges' questions or to provide supplementary data for the judges' consideration (the judges may only consider these data to discriminate between "tied" presentations)

Your team will have access to copying machines on Saturday only. One copy of all your presentation materials must be turned in to the event organizers not later than 7:30 a.m. Sunday. Event organizers will arrange for making viewgraphs (black on clear only) for your presentation and provide paper copies to the judges. (Any color viewgraphs must be hand-drawn with the viewgraph pens in your supply box, then make a black-and-white plain paper copy to include in your presentation materials submitted at 7:30 a.m. Sunday morning.) Presentations that do not meet the 7:30 deadline **WILL BE PENALIZED**--the later the submission, the more severe the penalty. Return all supplies (drafting tools, pens, etc.) to the event organizers with your presentation materials at 7:30 a.m. Sunday. **FAILURE TO DO SO WILL DISQUALIFY YOUR TEAM FROM THE COMPETITION!**

Originals of presentation materials must meet the following requirements:

- No more than 50 pages may be submitted
- All pages are standard 8.5 x 11 inch white paper, in order not to jam the copier's automatic document feeder
- If you draw something on non-standard paper or viewgraph transparencies, please copy it onto standard paper and submit the copy
- Make sure original artwork will show up on copies (verify pencil drawings are dark enough)
- The first page of your presentation materials must clearly show your company name

Any pages that do not meet these requirements may not be included in the Judges' copies. Only the first 50 pages of your presentation materials will be copied for the judges. The judges reserve the right to **DISREGARD ANY CHARTS NOT INCLUDED IN THEIR COPIES.**

## **Space Settlement Design Competition History**

Your presence here is part of a long history of Space Settlement Design Competitions.

It all started in 1983, when plans were being made by the Boy Scouts of America for the 1984 National Exploring Conference. The steering group for the Science and Engineering Cluster decided that it would be great to do something neat about space. Only problem was, nobody on the committee knew anything much about space (except that it was neat)--but Evelyn Murray from the Society of Women Engineers knew Anita Gale in California who worked on the Space Shuttle program. What followed was a series of letters recommending ideas and expanding ideas, and concluding with a phone call between Anita in California and Rob Kolstad (a member of the steering group) in Texas. During that phone call, they outlined the basic structure of the event, that it would be both a design competition and a management simulation game. Anita recruited her friend and fellow-volunteer-for-many-things Dick Edwards to help write the materials for the game, and the rest, as they say, is history. The first Space Settlement Design Competition was conducted at Ohio State University (between thunderstorms and tornadoes) in August 1984, with about 75 participants. It was wildly successful. Even astronaut Story Musgrave stopped by to watch design presentations.

The Explorers' Science and Engineering Cluster was so impressed by this event, they started working hard to make sure it would continue in some form. Eventually, Dr. Peter Mason and the Space Exploration Post at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, agreed to try it out on a local level.

The first SPACESET was held in 1986. Twelve annual SPACESET competitions have been conducted at JPL, with continuing participation by Anita Gale, Dick Edwards, Rob Kolstad (who now flies in from Colorado), and Peter Mason. As many as 160 young people participate each year, with a different design challenge each time. The competition organizers have requested Space Settlement designs in Earth orbit, on Earth's moon, on and in orbit around Mars, and on and in orbit around Venus (including some global atmospheric alterations to make the place habitable). One Earth orbiting Settlement was required to be able to move to another solar system; another solved a global warming crisis.

The first annual National Competition was organized when SpaceWeek International considered that a Space Settlement Design Competition would be appropriate to include in commemorating the 25th anniversary of the first lunar landing, in 1994. Astronauts and Cosmonauts recruited as volunteers for this event were so impressed with its educational value, they insisted that it be continued annually. Although it soon became evident that SpaceWeek International was unable to sponsor subsequent National Competitions, the promise made by Anita and Dick was accomplished in 1995 at Epcot in Walt Disney World, and the Third Annual Finalist Competition moved to an apparently permanent home at Kennedy Space Center in 1996. Any high school in the world is welcome to join International Qualifying Competitions, by accessing materials on the Internet at <http://space.bsdi.com>.

The concept has grown. The annual Antelope Valley Competition started in 1995 when Max Vallejo of Rockwell (now Boeing) learned that NASA-Dryden Flight Research Center desired to offer enhanced educational experiences to local students. A proposal to conduct a JPL-type Competition was submitted to Lee Duke, Education Functional Manager for NASA-Dryden, who authorized the event. In 1996, NASA-Dryden enlisted the help of Victor Valley College and the Apple Valley Science and Technology Center, to establish a similar Competition in the Victor Valley.

## REALITY VS. Space Settlement Design Competition

A statement you may hear several times during your Space Settlement Design Competition experience is "Now you know what it's like in industry!" This is, after all, an industry simulation game. You will have too much data in some areas, too little in others, not enough time to search out what data are available, personnel conflicts in your organization, technical conflicts between departments, difficulty in describing your entire design during the time allowed, and questions from the judges that you consider unfair (or "I forgot" revealed). All of these are challenges faced by real engineers in real companies (and have been faced by many of the adult volunteers you will meet). Of course, a lot of the Space Settlement Design Competition is pure fabrication: it describes, as history, things that haven't happened yet. So, what is real, and what is Design Competition speculation?

The basic products, vehicles, and structures described for the Space Settlement Design Competition are technically possible, within the timeframes indicated. They do, however, represent ambitious technical, economic, and political commitments. Some will never happen, some will. Some are projects that Design Competition participants who become engineers will work on during their careers.

The Design Competition companies, including their product lines and histories, are based on composites of real corporations, projected into the future. No Competition company, however, is based solely on a single real company. Company names were selected for humor and name recognition, and do not indicate any similarity to real corporations. The recommended Design Competition organization chart is a true reflection of part of a generic organization structure used by many companies.

There is no such organization as the Foundation Society (too bad!). The described efforts by the Foundation Society to foster commercial space infrastructure development could, however, be accomplished by other existing organizations.

The Request for Proposals and proposal process reflect, as closely as possible, the system by which real corporations propose and win contracts for new business.

Information about space, lunar, and planetary environments and resources is based on numerous references. Supplementary articles and other materials are genuine technical documents that have appeared in print, or were specifically prepared for the Design Competition but are based on serious research. Sources are clearly marked where possible, and have not been fabricated. "Department Descriptions" represent a summary of the types of tasks, analyses, and factors that similar real groups address.

Descriptions of specific future commercial products manufactured in space, space-based businesses, and health benefits of life in space are pure speculation.

Described missions to Mars do NOT reflect feasible mission dates, based on ephemeris data for the years described. Although it is theoretically possible to launch missions to Mars from Earth at any time, vehicles that depart Earth's vicinity at other than optimum Hohmann Transfer opportunities will require significantly more energy (fuel) and time to complete the journey.

The difficulties associated with Martian dust are real. The stuff is incredibly fine, gets into everything, has defied all attempts to completely remove it from anything that has been outdoors, and will ultimately destroy any mechanical equipment it gets into. Long-term habitations on Mars must take every grain of tracked-in dust very seriously, because a gradual accumulation over time could result in some very serious problems.

If, during this experience, you have any questions about the aerospace industry, feel free to ask your company's CEO or another adult volunteer--many of whom do the same things in real life that you have the opportunity to do here.

## HOW COMPANIES WORK

Projects as huge as the Space Settlement being designed for this competition are excellent examples of how large companies came into being.

For most of human existence, the things that people made and used could be produced by individual people, or by small groups of people who worked together as partners. Those items that were in broad use could be made separately by many such individuals or small groups in many locations; products like shoes, houses, weapons, wagons, and food products are in this category. Indeed, technology has usually been simple enough that if a product was required in a place, somebody could be found nearby who could replicate it. Many things that we now buy for personal use are things we might have made for ourselves only a hundred years ago--things like bread and other prepared foods, soap, candles, and clothing.

Exceptions to this "rule of small-group manufacturing" were large public works projects: government buildings, aqueducts, roads and street networks, city walls, bridges, and even cathedrals and temples. Through necessity for the public good, construction of these structures was controlled through government (including military) or church bureaucracies. These projects were, after all, too important to be left in the hands of private individuals, construction time was often longer than an individual's lifetime, and only a government or church had a large enough organization to have influence over the geographic locations and large numbers of people that were involved in supply and construction.

Advances in technology changed all of this. Products came into use that could only be made by machines, machines were developed that could do work better and more quickly than muscle, and quality could be achieved more consistently with machines. As these machines became more complex, they could not always be replicated by somebody in the local area. The small groups of people that could make them got requests for more and more, and from all over the nation and the world. Greater demands for the products meant that these organizations were encouraged to grow so that they could meet the needs of their customers--and many of these organizations became large corporations. The advent of these giants then made it possible for single organizations to complete huge projects, including skyscrapers, supertankers, supercomputers, jumbo jets, giant rockets for launching tons of payload into space, and even entire cities in the Middle East. When companies find that they do not have all of the people or facilities required to perform such feats, they team up with other companies to combine resources.

As organizations grew, they had to adopt new ways of doing business. The boss no longer knew everybody, directed each person's work, and worked right alongside the employees. Whole new careers and kinds of work had to evolve. Work was divided into that which was done by the managers, and that which was done by the common laborers. Administrative positions developed to handle finances, hiring, advertising, and even making sure everybody got a paycheck. Companies found themselves in a situation where they could have a perfectly good product, and still fail--through faulty management.

As this was occurring, there were no historical precedents to guide the participants. Their primary priority was to get the products out the door, and on-the-spot innovation was used to form an organization that could do the job. Under the circumstances, the organizations that evolved adopted patterns that were familiar to the people who were arranging them--military patterns that had been used for millennia to coordinate the efforts of huge numbers of people. This worked reasonably well in early corporations, because the intelligence to run the business resided at the top, and the other folks could do their jobs adequately just by following orders.

In only the past few decades, the nature of the products produced by large corporations has been changing, and their organizations have been evolving to adapt. To stay in business, corporations

must now rely on the intelligence of employees at all levels--not just at the top. Strategic planning, corporate philosophies, and competitive positioning are still defined by top executives, who must make sure that the lower echelons understand their duties to implement them. These top executives must also make sure that they have good communication up from the lower ranks, so that they know what is going on--especially if a problem arises that demands high-level attention. The greatest changes are occurring at the bottom rungs of corporations, where the population is becoming dominated by "knowledge workers" instead of common laborers. These include researchers, product designers, and computer programmers who determine the very nature of the products that can be offered by the corporation.

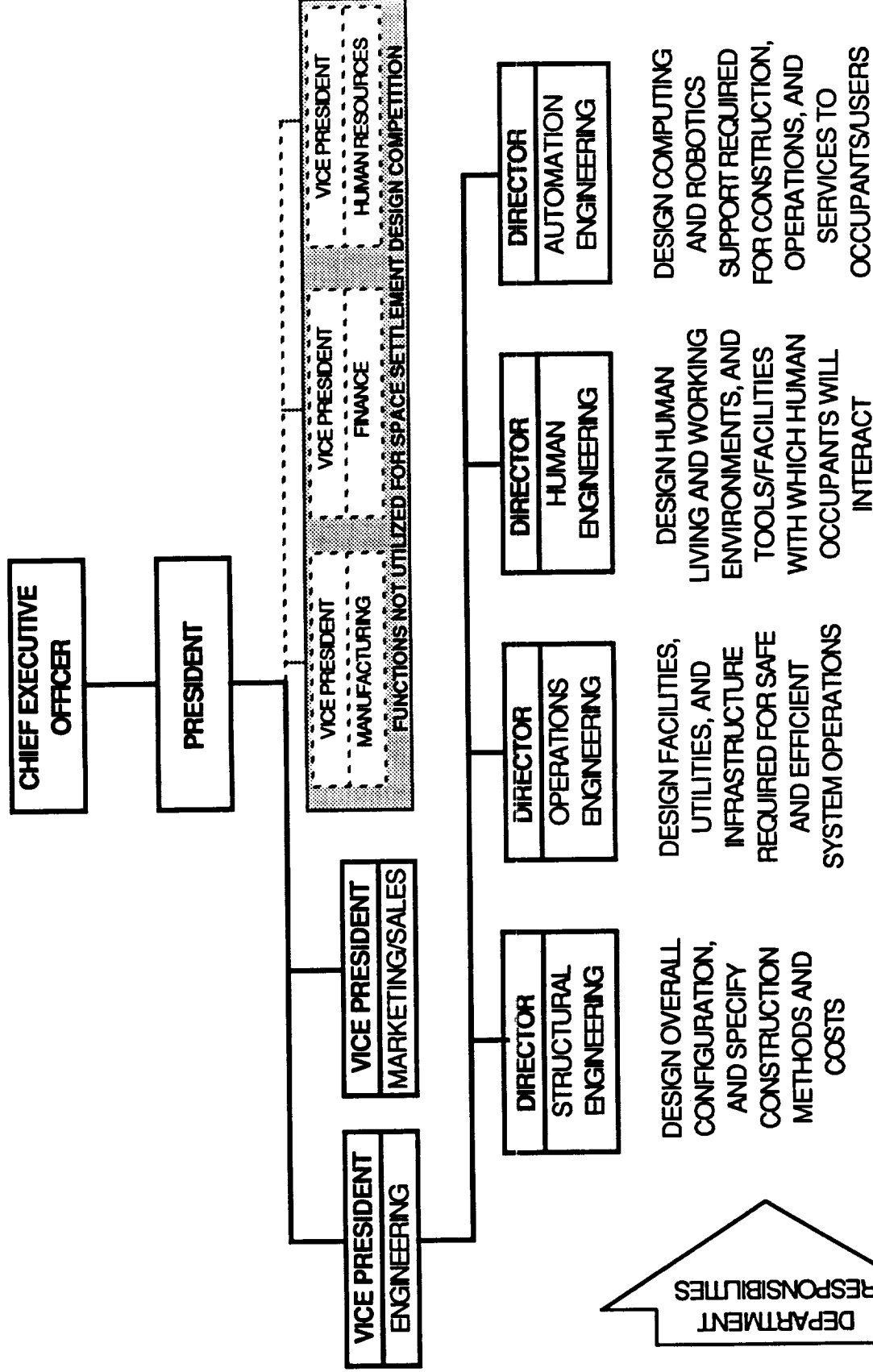
The whole science of management is changing to accommodate this new type of employee. It includes recognition that communication is the lifeblood of the organization, each individual employee has unique skills to offer, employees at all levels are more productive if they enjoy their work, and employees enjoy their work best when they feel it is important.

Communication is the greatest challenge faced by top management. The sheer size of some organizations illustrates the problem. A typical organization has a small group of officers including the Chief Executive Officer, Chief Operating Officer, and Chairman of the Board; reporting to these are Division Presidents, to whom report some Vice Presidents, Directors, Managers, and Supervisors. Below the Director level, eight to fifteen individuals of the next lower rank may report to the higher level. A Vice President-Engineering for a very large division may have five Directors, 50 Managers, 600 Supervisors, and 9000 engineers and other technical people. Employment of 10,000 to 20,000 individuals at one plant is not uncommon. Some corporations have dozens of divisions world-wide, and employ hundreds of thousands of people. Even in the same building, everybody does not know everybody else. Effective operation of the corporation requires, however, that people working on different parts of a project share information about it. Sometimes a problem on one project can be solved by a person who has had similar experience on another project. The "perfect solution" has not been found, and companies still find themselves making parts that don't fit, designing products that can't be maintained, creating destructive software, and even forgetting to complete contracts.

Professional people are also expensive. Typically, a company pays \$125,000 to \$150,000 each year for the salary, benefits, floor space, furniture, supplies, repro machines, utilities, telephone service, and other overhead to support one engineer. "Overhead" includes secretaries, janitors, guards at the gates, the fire department, the first aid station, and the computers.

This all seems very intimidating to the individual who has just accepted a first job in a huge corporation. Fortunately, most modern corporations are friendly places where new employees are helped to adapt as quickly as possible--it does, after all, help the company to make you productive with minimum delay. There are several phases to this absorption of new employees. On the first day, your primary interest is to figure out how to find the (correct) restroom, the route from your desk to the door of the building, the route to the gate of the plant, and how to find your desk from whatever location you find yourself in when you realize you are lost. Your first work assignments will be relatively straightforward tasks you were hired to do. If you get stuck, you will find lots of other people in your group, including your supervisor, who will show you "the company way" or the right people to help you accomplish your tasks. After one to five years, your performance on projects will lead to your establishing your niche in the organization, and in four to ten years you could become an expert in your field. In all of your work, you will become more valuable as you know and are known by more people with other special skills or knowledge.

# COMPANY ORGANIZATION CHART



DEPARTMENT RESPONSIBILITIES

## **Space Settlement Design Competition STANDARDS OF PROFESSIONAL CONDUCT**

Victor Valley College and the Apple Valley Science and Technology Center have generously allowed us to use their facilities for the weekend. In return, they have established some guidelines that we need to follow while we are here:

1. Smoking is not permitted inside any buildings in which Space Settlement Design Competition activities take place. Consumption of alcohol is not allowed at any time during the weekend. Design Competition participants are expected to abide by all laws enforced in the city of Victorville.
2. Leaving the Competition sites during the weekend is strongly discouraged; only participants who have turned in a Home Permission Form signed by a parent will be allowed to leave the Competition before it ends. If you find it necessary to leave the Competition during the weekend, you must check out either with the Registration Desk, or with a staff member on duty at the College gym during the night. If you leave without checking out, we will assume that you have forfeited your place in the Competition.
3. Some facilities of Victor Valley College operate seven days a week. Please do not venture out of the areas designated for Design Competition participants.
4. You may encounter equipment operating unattended. Do not touch any equipment that has not been allocated to the Space Settlement Design Competition. If you are not sure if a piece of equipment is intended for use by the Competition, please ask a staff member.
5. Eating and drinking are not permitted on the main floor of the gym. Please ask a staff member where eating and drinking are allowed indoors.
6. People desiring to remain awake after the lights go out in the gym should go to an area designated by a staff member on duty at the gym. Out of courtesy to those who wish to sleep, please try to keep the noise level down. NOTE: while you may continue to work on your company's presentation after returning to the gym on Saturday night, your company's computer equipment may not be removed from your company headquarters. Schedule your work on the computer so that it is completed before you leave your company headquarters Saturday night.
7. Separate sleeping quarters are provided for the guys and the gals. Guys are not allowed in the gals' sleeping area, and vice versa.
8. Competition staff members will be available at all times, either at the Registration Desk or in the gym. If a circumstance arises that is not explicitly covered by these guidelines, please ask a staff member, and/or use common sense in your choice of actions.

**Remember, you are a professional now.** Your cooperation in following these guidelines is greatly appreciated. Your responsible behavior will enable use of these facilities for future Space Settlement Design Competitions.

## SPACE CHARACTERISTICS AND RESOURCES

Space is not a friendly place. Mostly, it is nothing: vacuum, and apparent lack of gravity. What little there is in space is mostly hazardous, even the things that are assets.

One asset abundant in space, at least out to Mars orbit, is power, in the form of energy from the Sun that can be converted into electricity. The supply of power from the Sun is continuous and uninterrupted, and it is 6 to 15 times as intense in Earth orbit as on the Earth's surface (solar energy intensity is absorbed by Earth's atmosphere). Solar energy does, however, present hazards, in that it is harmful to humans who are not shielded from it. The Sun is also the source of flares producing intense radiation which is deadly to unprotected humans. The Sun is not the only source of hazardous radiation in space; cosmic rays, gamma rays, and X-rays are also part of the ambient space environment, at sufficient intensities to be damaging to humans.

The primary law of space is Orbital Mechanics, which determines where things can stay and where they can go. Everything in space is moving, attracted by gravitational fields (usually interacting) of every major object in the vicinity. Which orbit an object is in depends on its position and velocity at any particular time. Orbits are changed with acceleration due to thrust, usually from rockets. Satellites are constrained to be far enough above most of any atmosphere that an orbit can be sustained with minor altitude decay due to friction with the atmosphere. Objects with bigger cross-sections experience faster orbital decay. Higher velocities put objects in higher orbits; an object achieving "escape velocity" (25,000 mph for Earth) will leave the influence of its "host", and go into orbit around something else. Orbits are also not perfectly stable. Satellites use small rockets for "station-keeping" to stay where desired. Some quirks of orbital mechanics cause gravitational forces of large bodies to be in balance at some locations, creating "Libration Points" that are either very stable (L4 and L5) or are unstable in one plane (L1, L2, and L3), and require substantial station-keeping to maintain spacecraft in position.

Solid objects in space are also both hazards and assets. Debris is a nuisance: at orbital velocities, even paint flecks can do damage, and small bolts or rocks can puncture spacecraft cabins. The Moon and asteroids, however, represent vast reserves of relatively easily accessible resources; getting to them requires much less energy than launching materials from the Earth. The lunar surface is 99% oxides, of silicon, iron, aluminum, calcium, magnesium, and titanium. Asteroids are of several types, and can contain nickel, iron, water, carbon, and carbon compounds. Comets typically move faster and are harder to capture, but contain substantial reserves of water ice.

There are some similarities between Mars and Earth. Martian days are just 37 minutes longer than days on Earth. The surface area is nearly identical to the land area of Earth. There are many land features (mountains, valleys, cliff faces) like familiar ones on Earth, although the most spectacular are ten times taller, wider, and deeper than their Earth counterparts. Resources are abundant: the Martian atmosphere, though less than 1% the density of Earth's, is 95% carbon dioxide and almost 3% nitrogen. Water ice is present in the North polar cap, and surface components include silicon, aluminum, iron, magnesium, and calcium. There is, however, an eerie otherworldliness about the place, too. There is gravity, at 38% of the force on Earth's surface. The sun is pale and cold, providing only 36% of the energy available for the same area of solar panels in Earth orbit. The two moons are tiny and close; one crosses the sky three times per day. There are seasons, in a year nearly twice as long as Earth's, with a much harsher climate in the southern hemisphere. There is a South polar cap, but it consists of carbon dioxide ice. The surface environment is hardly more hospitable than empty space. It is cold on Mars, with an average surface temperature of  $-60^{\circ}\text{C}$ , and the warmest temperature barely above freezing. The radiation hazard is nearly the same as in space, because the negligible magnetic field and thin atmosphere offer little protection. Winds that blow up to hundreds of miles per hour can hurl dust with sandblasting ferocity, and cause global dust storms that last for months.



## EXISTING SPACE INFRASTRUCTURE

Earth orbit in 2047 is a very busy place, with thousands of automated satellites serving the seemingly insatiable appetite of the terrestrial population for communication, navigation, observation, materials processing, manufacturing, energy, and tourism.

Most of the demand for satellite locations has been in geosynchronous orbit, where even the closer spacing allowed by improved signal separation technology in the late 1990's did little to relieve the competition for communication satellite "slots". Resolution of this problem was finally achieved with the development of geosynchronous antenna "farms" up to a kilometer long, each of which supports equipment that would otherwise have required dozens of separate satellites. Solar Power Satellites are not subject to spacing restrictions, and occupy GEO between antenna farms.

Low Earth orbit is primarily occupied by resort hotels and successors to the original three Space Stations (now spaceports) established by the United States and some international partners after the year 2000. Regular passenger and cargo service is available to all three ports from eleven locations on Earth's surface, with launch costs, including insurance and payload integration costs, averaging \$600 per lb. for first-time payloads, and \$550 per lb. for repeat payloads. The spaceports are at 250 miles altitude; most launch vehicle traffic from Earth still goes through these ports, where goods and passengers are transferred to ships more appropriate for operations in space. Several other large orbiting spaceports have been established between 55,000 and 100,000 miles altitude, to provide satellite maintenance and construction services. Space tugs are available to move satellites between orbital locations

The largest orbiting space operations are the settlements established by the Foundation Society, which have been placed in orbits around the L5 and L4 libration points. The Settlements provide safe and pleasant living and working environments for communities of 10,000 to 20,000 full-time inhabitants each, and up to two thousand visitors. The inhabitants are fully employed maintaining and operating their Settlements, and producing products as needed by the communities and for trade. The orbiting Settlements have port and cargo-handling facilities that are available for transferring goods and materials between ships. Alexandria was expanded from its original design, and a decade ago founded the University of Space Science and Technology, to service the research and higher education needs of the growing spacer population.

The first lunar outpost was established with missions using spacecraft assembled in orbit with components launched on two different Reusable Launch Vehicle (RLV) flights, in the year 2008. During the next decade, two other bases began operation, each with a staff of between six and fourteen people. Their exploratory expeditions confirmed both the abundance of lunar minerals and oxygen compounds, and the near absence of hydrogen, nitrogen, and carbon. Although water ice was found in deposits in the eternal shade of a south polar crater, the quantity was insufficient to sustain large-scale human operations. The Foundation Society is leading large-scale Lunar development, having established a surface settlement for 8000 residents, with facilities for up to 2000 visitors. A second settlement began occupation in 2041. Regular passenger and cargo service is available to the two Foundation Society sites on the Moon.

Despite successful completion of manned missions to Mars in 2019, 2016, 2030, and 2034, and 15 years of mining operations in the asteroids between the orbits of Mars and Jupiter, only the Foundation Society has demonstrated an interest in establishing a large-scale human presence on the planet's surface. Although the Aresam settlement will not be ready to support large-scale surface activities until 2052, it has been providing expanding services to asteroid mining operations since 2044, and serves as a base for the Foundation Society's ongoing small survey missions to the Martian surface.

## THE CUSTOMER

The FOUNDATION SOCIETY is an organization founded for the specific purpose of establishing settlements of its members in space. In the mid-1990's, it led several grass-roots space advocacy organizations in fostering development of commercial infrastructure in Earth orbit, by researching profit potential for launch vehicles providing lower costs per pound to orbit. The Society assured that new launch vehicles would have customers, by providing venture capital for companies developing new products that utilized or required launch services. The Foundation Society funded lobbying in Congress that resulted in favorable tax and equity-protection laws for companies investing large percentages of their assets in perceived high-risk ventures with long-range return, further assured a strong customer base for commercial launch services with long-range commitments for government-sponsored scientific and exploratory space missions, and removed the government from the businesses of launch vehicle operation and space hardware fabrication. The results of these efforts encouraged American corporate interest in commercial development of the launch vehicles and space infrastructure that have made large-scale access to space practical.

The Society began operation of its first settlement for 10,000 of its members in Earth orbit late in 2012. The second Foundation Society orbiting settlement began occupation in 2022, and a third began occupation in 2030. Since that time, two settlements on the lunar surface have been completed (2027 and 2041), and a settlement is nearing completion in Mars orbit. Plans are in various stages of development for more large space settlements; this expansion of infrastructure will continue as long as promising new sites are available, and economic reality permits. The Foundation Society intends that each community eventually be self-supporting through trade and services it can offer to Earth and other bases and settlements. [Note: the Foundation Society has established a convention for naming the new communities it creates, allowing initial residents a personal choice in selecting names for their cities, yet providing some traceability of place and history. A suffix indicates location, and communities with the same suffix receive names in alphabetical order. Hence, the three Earth-Orbiting settlements were named Alexandriat, Belvestat, and Columbiat ("at" = "(in orbit) around Terra"). The two communities on the lunar surface are Alaskol and Balderol ("ol" = "on Luna"). The first settlement in Mars orbit is "Aresam". For contract award purposes, the first Mars surface settlement is called "Argonom", although its occupants have not yet been selected and the name has not been finalized.]

Although the Foundation Society has developed sufficient financial reserves to invest in expensive projects like Space Settlements, the organization's goal is to build as many as possible, and therefore to develop an efficient construction infrastructure. To this end, lunar materials have been utilized extensively in the existing settlement designs. Lunar concrete has proven to be an excellent shielding and building material when used in compression applications. A high-quality lunar glass is made in Foundation Society facilities at Columbiat; although it does not provide shielding, it has superior optical characteristics and carries both compression and tension better than Earth-supplied equivalents. An iron-nickel asteroid was delivered to Belvestat, and harvesting operations are currently processing several tons of ore per day.

Members who occupy each settlement have earned the privilege through substantial investments of financial resources, frequently in combination with contributions of property, materials, capital equipment, and services. Most of the individuals who have been able to afford Foundation Society membership have acquired their wealth either through family resources, or through successful entrepreneurial enterprises. Those who have augmented less substantial financial resources with "intelligence equity" are primarily professionals, with a high percentage of engineers, scientists, and technicians. Some residents of existing settlements are operating businesses there; their products are almost exclusively "soft goods" that can be transmitted by data link (e.g., software, research results, text).

Most of these people are Americans; the non-Americans in the Foundation Society's existing and planned communities have either lived or traveled extensively in the United States. A primarily American culture prevails in the current Foundation Society communities, although each settlement has acquired its own unique personality.

## **DOUGELDYNE ASTROSYSTEMS**

Located in Bellflower, California, Dougeldyne AstroSystems is the world's most prolific manufacturer of unmanned space systems. With humble beginnings as a builder of aircraft parts and industrial tools, the company entered the spacecraft business in the early 1960's with a reputation for quality manufacturing of specialized products, and a few key employees.

Although Dougeldyne built the whole gamut of unmanned satellite systems, for military, scientific, NASA, and commercial customers, the company's reputation in the aerospace industry was primarily established through its development of communications satellites. Since the 1980's, the company has offered satellites designed for different parts of the space communications market. Upgrades usually kept these products slightly ahead of competitors' technology developments, with new generations of capability available every four to six years. Indeed, the company's rapid technology improvements were largely responsible for the industry's recognition in the mid-1990's that satellite "slots" were more valuable than the satellites themselves. Satellite construction costs were subsequently reduced by a factor of three through reduction of redundancy and robustness. Dougeldyne did pioneering work in development of antenna "farms", and was prime contractor for construction of four of these projects. The company now builds, installs, and services many of the communications systems that are installed on the antenna farms.

A spinoff from Dougeldyne's satellite business was a very successful research program in solar panel technology, which the company capitalized on in winning the contract to develop the solar power system for the first International Space Station. A breakthrough in solar cell efficiency reduced required solar panel area by half, new materials technology extended average solar panel lifetime on orbit by six years, and cost per watt was reduced to 30% of that previously required through innovative improvements in production efficiency. Since 2018, Dougeldyne has been producing space-quality solar panels for \$50 per kilowatt in its lunar-orbiting manufacturing facility. The company thus established itself as the primary supplier of solar panels for spacecraft and space-based systems, and maintains this position with a vigorous and successful research program.

Improvements in solar panel fabrication techniques reduced production costs enough to justify construction of company-owned Solar Power Satellites beginning in 2006. The company built a 100-megawatt prototype, but was unable to attract customers for larger versions when problems developed with the equipment that converted the collected power into microwave energy for transmission to users. Although this challenge was eventually solved, large utilities remained unimpressed. Dougeldyne continued with the project anyway, and began selling surplus power from a two-gigawatt installation completed in 2011 to the same "dirtside" utilities that refused to support it. Subsequent Solar Power Satellites have been built to supply Foundation Society settlements and other large on-orbit facilities. Completion of the Lunar Polar Power Plant in 2025, and the company's willingness to expand its power-distribution infrastructure to support customers' projects, enabled significant cost and complexity reductions in the designs of the Foundation Society's Alaskol and Balderol settlements.

Dougeldyne is also a provider of launch and orbital transfer services for space cargo, having recognized that its dependence on the availability of other organizations' launch vehicles and launch sites had the potential to jeopardize its ability to sell satellites. The company owns a modest fleet of launch vehicles and space tugs purchased from Grumbo, and operates a launch site on a large platform at the Equator in the Pacific Ocean. A small fleet of ships transports payloads from San Diego, California, to the launch facilities.

Dougeldyne executives aggressively sought--and won--the Columbiat contract as a means to break into the manned spacecraft market, after they became concerned that the company's concentration on unmanned satellites could be detrimental in the future business climate. The company is teamed with Flechtel Constructors to make up for its lack of expertise with human factors and expects this partnership to be a strong competitor for the "Argonom" contract.

## **FLECHTEL CONSTRUCTORS**

Although its corporate offices are formally located in New York City, Flechtel Constructors has offices in cities around the world, which operate nearly autonomously.

The company has been in business since the 1920's, when it designed and built facilities for energy and chemical companies. Until the late 1960's, Flechtel products were primarily oil refineries and factories producing industrial chemicals, fertilizer, and household cleaning products. The company has skills, however, for designing nearly any industrial, commercial, or government facility, and has been involved with concepts for power plants, ground transportation infrastructure, farming, logging, amusement parks, harbors, and airports. In the 1970's, the company was known for its contracts to design entire cities in the Saudi Arabian desert, including airports and water desalination plants. Flechtel expanded rapidly during the 1990's with contracts to upgrade Russian and Kazakhi oil industry and petrochemical plants, modernize the ground transportation infrastructure of Russia, Ukraine, and (European) Georgia, clean up environmental damage in Eastern Europe and Northern Asia, and rejuvenate several Eastern European cities. In the 2010's, Flechtel designed and built the Kenyan veldt launch site and Dougeldyne's Pacific Ocean launch site, and has since assisted with upgrades to these facilities to accommodate new launch vehicle designs. A large percentage of its business in the 2020's resulted from its leadership in developing designs for modifying airport facilities to service aircraft with cryogenic fuels. A consistent company philosophy is that every customer is important, and no project is too big, too small, or too strange.

Low-cost and high-quality construction techniques, developed during the post-Soviet construction boom, were applied after the year 2000 to bring about rapid development in developing countries. The company began assisting poor nations by entering into joint ventures to develop capital-earning industrial bases through construction and operation of factories exploiting each nation's workforce skills and natural resources. Successful operations of these ventures are assured by Flechtel employees who stay with the plants through start-up, conduct training programs for local workers, and periodically return to see that no problems are developing, and to introduce improvements in plant operations. This program so greatly benefited developing nations that Flechtel was awarded a Nobel Peace Prize in 2011.

The company again gained humanitarian recognition in the 2030's, when it developed a design and demonstrated feasibility of operating huge ocean farming systems. Other companies have since developed their own designs for these facilities, and now dozens of them are operating in remote deep-water areas of the Pacific and Indian Oceans, far from land and pollution. Isolation from contaminants enables farm operators to better control nutrients provided to fish and aquatic vegetables, and to better control diseases. The development of these farms has assured virtually inexhaustible food supplies for Earth's peoples.

Flechtel has been associated with the aerospace industry since the late 1980's, when it assisted Grumbo Aerospace with some research into requirements for construction of human habitats on the lunar surface. This work was of very high quality, defining standards for light filtering and radiation shielding for different types of human activity on the Moon. Flechtel has since been involved in some way with every lunar habitat construction project. As a subcontractor for the U.S. lunar bases, the company designed and constructed living area interiors, and was more successful than other companies in developing dust control systems. Flechtel engineers did conceptual design for port facilities at the Foundation Society's Alaskol settlement and built the extensive tourist facilities adjoining Balderol. The company worked on a major contract from the U.S. government to do advanced studies of lunar infrastructure requirements.

Flechtel is currently teamed with Dougeldyne AstroSystems in the competition to build the Foundation Society's "Argonom" settlement, reviving a relationship that won the contract to build the Foundation Society's Columbiat settlement. Dougeldyne's experience with orbital systems provides a strong complement for Flechtel's experience with habitats on the lunar surface.

## GRUMBO AEROSPACE

Grumbo Aerospace, a division of Grumbo International, is located in Augusta, Maine. Aerospace is one of Grumbo International's four major business groups.

Products of the General Industries business area include F1M8 Robots. Although they service a variety of commercial and domestic applications, F1M8s all share a proprietary "artificial intelligence" capability that enables them to recognize commands in human speech and "learn" through experience. In 2042, Grumbo upgraded robotic operations at the Foundation Society's lunar mining facilities; when the new robots harvest the ore, they extract and process materials from which they produce ore-carrying cars that transport raw ore to the primary refinery and distribution center. In this operation, the cars themselves are actually a pre-processed part of the mined shipment.

Among the achievements of the Electronics Systems Group was development of the chips and software that enable billboard companies to reprogram displays on any of their roadside billboards anywhere in the world from one central command location. This capability changed the sign industry; some billboards are completely changed several times per day, according to anticipated demographics of travellers on adjacent roadways. The company also pioneered computer file technology that changed the way documents are filed in offices; paper copies of reports and documents are now virtually nonexistent, since Grumbo's development of circuitry for computer disk "file cabinets". These resemble old-style 5-drawer cabinets for paper files, and remain inert (draw no power) until the user requests a file--at which point only the "drawer" containing that particular file in the "file cabinet" is activated and accessed by the user's computer.

The Ground Transportation Group successfully transitioned to supply products for the first Ground Effect Machine personal vehicles and magnetic engines. This segment of the company also built several vehicles customized for operation on the lunar surface, with technical assistance from the Aerospace division. Grumbo vehicles are in use at the Alaskol and Balderol settlements, and are utilized for exterior (primarily maintenance and repair) tasks on all of the Foundation Society's orbiting settlements.

Early products of Grumbo Aerospace included expendable launch vehicles (ELV) and upper stages to transfer payloads from low Earth orbit (LEO) to geosynchronous Earth orbit (GEO) and other high-altitude orbits. ELV markets dwindled after 2010 and disappeared by 2020; the company ceased production of upper stages in 2026. The ELV and upper stage production facilities were, however, re-tooled for building components of orbital transfer vehicles and space tugs; the components are launched to Grumbo's LEO factory, where they are assembled into vehicles optimized for operating in space.

The company's most well-known product is the Reusable Launch Vehicle (RLV), which began service in 2006; this was the first commercial vehicle based on X-33 technology. The vehicle launched up to 25,000 lbs. to the existing spaceports, and 43,000 lbs to 160-mile LEO. This 200-foot-long vehicle also pioneered development of the 45 foot long by 15 foot nearly square cross-section space cargo containers now standard for all medium-size launch vehicles. RLV was briefly threatened by competition from the more economical Condor, built by Vulture Aviation, when it entered service in 2013--until commercial operators realized that there was plenty of launch business for fleets of both vehicles. Grumbo also developed the "Grumbo Jumbo", a heavy-lift reusable Single Stage to Orbit design (up to 100,000 lb. payload) that captured a significant share of the commercial cargo market when it went into operation in 2017. The Grumbo Jumbo tapped into a huge market for space-based disposal of hazardous wastes, which became lucrative with launch costs below \$500 per pound. Grumbo now sells several different versions of both vehicles, with RLV capability up to 55,000 lb. to the spaceports, and Grumbo Jumbo capability to 175,000 lb.

Grumbo participated heavily in early space settlement studies and independent research. This commitment was a significant factor in the Foundation Society's selection of Grumbo to build Bellevistat, completed in 2022, and Balderol, which began occupation in 2041. Company officials feel they have established a reputation with the Foundation Society that puts them in a good position to win the "Argonom" contract.

## ROCKDONNELL

Corporate Headquarters were moved to an orbital location dubbed "Rock-in-the-Sky" in 2020, in order to be closer to where the company does business in Earth orbit. Rockdonnell was formed as a joint venture between two major firms, for the purpose of winning the first Foundation Society Space Settlement contract.

Rockdonnell did win the first Foundation Society Space Settlement contract, and in 2012 successfully completed Alexandriat. The company continued its relationship with the Foundation Society with completion of Alaskol in 2027. When the Foundation Society decided to modify and expand Alexandriat in the late 2020's, Rockdonnell created the designs and managed the construction process.

One parent company is a large and successful aerospace firm with several divisions. Spacecraft built by the Spacets Division include asteroid retrieval hardware utilized by Bellevistat's highly successful mining operation, zero-g refineries for extraterrestrial materials, and small Mars landing vehicles based at Aresam and used for the Foundation Society's planetary surveys. The Rockonetics Division is the major producer of engines for the aerospace industry, having established its reputation by developing the first air-breathing engine that could honestly achieve Mach 25 in the upper atmosphere, which ultimately resulted in Vulture Aviation's Condor launch vehicle. The Compsec Division produces 15% of the supercomputers used by the aerospace and entertainment industries, and has just introduced the third in a line of "micro-abacus" computers, advertised as fast, rugged, and transportable. An especially appealing feature of these machines is that they can be customized to fit particular applications; they are built up of small modules that can be separated or combined to provide capabilities ranging from workstations to sophisticated mainframes.

The other parent company is a large diversified firm with interests in oil, real estate, and hotels. It also leases communications services to governments of two dozen developing countries, through communications facilities it owns on six antenna farms.

Several Space Station experiments owned by the aerospace parent company led to identification of promising space manufacturing opportunities. These were offered to other corporations by Rockdonnell on the condition that Rockdonnell design, and build on-orbit space factories for commercial production of these products, and that 2% of profits from these operations be paid as a royalty to Rockdonnell. This venture has been very successful, with dozens of space facilities manufacturing pharmaceuticals, electronic components, genetically engineered organisms, and other high-value, low-weight-and-volume products; more are under construction or in the planning stages. This capability is especially attractive for genetic engineering projects, which are prohibited by many nations on Earth that fear ecological damage if a process goes awry.

With Rockdonnell's success, the two parent companies have frequently embarked on other joint projects. The most well-known of these is Icarus Inn, a private spaceport and resort hotel in Earth orbit that opened in 2013. The company used very aggressive marketing strategies to establish a public image for providing the ultimate in "status" vacation opportunities. All of the private suites are designed to provide stunning viewing of Earth below, and cater to guests' preferences to stay in zero-g, one-g, or intermediate acceleration environments. The venture proved successful, inspiring Rockdonnell to develop the more opulent Daedalus Resort that opened in 2025, and the family-oriented Helios Habitat which started entertaining guests in 2033. Since then, the company has opened a new on-orbit resort every five years, and plans to continue developing new properties--each with a different theme or guest demographic target--at five-year intervals indefinitely.

Observation of some long-term elderly guests who favored low-g suites led to research that showed slowing of the aging process and cessation of the progression of Alzheimer's disease in low-g environments. As a result, Rockdonnell established Sun-Up City in 2028, a retirement community that offers low-g residences and a slightly oxygen-enriched atmosphere to promote longevity and health.

Rockdonnell sees the "Argonom" Space Settlement contract as a logical extension of its successful work with the Foundation Society.

## **VEREINIGTEN FLUGFAHRTEN GmbH**

Located in Munich, Vereinigten Flugfahrten is a major aircraft builder, and the European Community's largest spacecraft manufacturer. The company also uses its excellent metals fabrication facilities for subcontracts in other product lines; it has manufactured door panels for the European model of Ford vans, housings for household electrical appliances and commercial test instrumentation, and components for high-speed trains.

The company entered the spacecraft market in the 1970's; its products have included satellites for a wide variety of applications, upper stages for satellites launched by Ariane launch vehicles, and subassemblies for the Ariane rockets themselves. In the early 2000's, the European Community opted to fund production of a vehicle derived from Vereinigten Flugfahrten's Sanger Spaceplane design. Sanger successfully met design objectives, although its small payload capacity (1500 lb. to Low Earth Orbit) restricted its commercial value. Experience with Sanger in hypersonic flight did, however, lead Vereinigten Flugfahrten to develop by 2009 commercial aircraft that cruise at Mach 5, which beat the American entry into this market by three years. In 2021, the company replaced Sanger with Weltraumreiseflugschiff, which entered service by providing charter flights for commercial space operators and for the European and Japanese tourist markets. To compete with other SSTO manufacturers, the company now offers a family of launch vehicles with payload capabilities to 80,000 lb.

The company's major launch vehicle customer is European Space Lines, which provides passenger service to orbiting hotels that cater to guests from Europe, Africa, and developing countries. Vereinigten Flugfahrten and ESL entered into a partnership in 2028, in order to develop the South Saharan launch site. Vereinigten Flugfahrten provided technical support and construction management to assure that passenger terminals, cargo loading equipment, and maintenance facilities would be completely compatible with all models of the Weltraumreiseflugschiffen. European Space Lines manages the launch site and operates all passenger and cargo handling services, including scheduling and service agreements with conventional ground transportation services and airlines that deliver passengers and cargo for transfer to launch vehicles. Vereinigten Flugfahrten provides maintenance and repair of the launch vehicles, which are owned by ESL.

Vereinigten Flugfahrten has a tradition of success that relies on self-sufficiency within the corporation. Because of this, it is involved in making many products that most spacecraft manufacturers would acquire through subcontracts. One of the consequences of this policy was the company's own development of computers and cockpit displays installed in its launch vehicles. An internal "Synergy Department" adapted some of the vehicle computer technology to develop new computer systems for use in office areas, whereupon the Marketing Department recognized a commercial product opportunity. As a result, a Vereinigten Flugfahrten subsidiary surprised the global computer industry in 2024 when it introduced computers built into office desks, with a screen occupying the entire desk top. Touch-screen control of files enables handling computer files like papers on a desk, with many documents visible and "shufflable" simultaneously. It took computer companies almost a year to introduce competing products, by which time Vereinigten Flugfahrten had established itself as one of the world's leading computer makers for the retail market.

Vereinigten Flugfahrten also built European modules for the International Space Stations and lunar bases. By including some company-owned materials processing experiments in these modules; the company developed extensive expertise in producing a wide variety of products in microgravity, and in extracting useful materials from lunar ores. The company is known to use some products from these ventures in its satellite projects, and a few very high-quality optical products and electrical components have been sold to selected customers. The company surprised the world-wide retail optical products market with its introduction in 2015 of "soft glass", which enables space-manufactured contact lenses to offer the comfort of soft lenses with the easy care and optical clarity of hard lenses. In order to assure complete privacy in its development of space-manufactured products, Vereinigten Flugfahrten established its own orbital manufacturing and research facility in 2023.

Always on the prowl for new markets, and fearless about challenging established industry leaders at their own games, Vereinigten Flugfahrten sees the "Argonom" contract as a prime opportunity for developing a new customer base and business area--and to gain access to the unlimited resources of Mars.

## VULTURE AVIATION

Corporate Headquarters are located in Issaquah, Washington, with manufacturing facilities primarily scattered around Washington State's Puget Sound area. Vulture Aviation is the world's largest aircraft manufacturer, having built 70% of the commercial jet, propfan, and supersonic aircraft operating in the world.

New (and proprietary) techniques invented by the company to increase airframe service life led to saturation of markets for new aircraft about 15 years ago. Company revenues due to aircraft sales have been stagnant since nearly all major airlines completed adding the new-technology aircraft to their fleets. When Vulture Aviation recognized 20 years ago that this trend was starting, its executives resolved to diversify their business, and become a full-service aerospace company. This was accomplished with the purchase of Consolidated Dynamics, a respected but poorly managed manufacturer of satellites and orbital transfer vehicles, in 2034. The strategy paid off; the expanded Vulture Aviation won the Foundation Society's contract to build Aresam.

Under Vulture Aviation's ownership, the old Consolidated Dynamics divisions improved their traditional products, but also adapted them; Aresam and the Foundation Society's interest in Mars provided opportunities to develop entire constellations of communications, navigation, and observation satellites in orbits around Mars. In order to provide transportation to Aresam, Vulture Aviation built four large "cycler" spacecraft, which are in elliptical solar orbits that cross the orbits of Earth and Mars when the planets are relatively close by. Transfer ships rendezvous with the cyclers to load and offload cargo and personnel. These ships remain the only means of transportation between Earth orbit and Mars.

Several wholly-owned subsidiaries provide missile range operation and maintenance for the U.S. Air Force and European Community Air Defense Command, fishing equipment, and energy conversion systems. Projects in the latter business area include energy production from swamp vegetation, solid waste products, tidal action, and windmills. A research division stunned the scientific community last year by successfully generating and containing small black holes; a variety of commercial uses of this technology is being investigated, so far inconclusively.

Outside of the aircraft business, Vulture Aviation is most well-known for its single-stage-to-orbit manned launch vehicle, the Condor. In 2008, when it became clear that the Rockonetics Mach 25 engine was reliable enough to support commercial operations, the company committed to development of a vehicle with 25,000 lbs. payload capability to LEO. Customized versions entering service beginning in 2013 assured profitability for fledgling earth orbiting manufacturing and commerce facilities. Condor offered launch services at \$550 per pound, with discounts to \$500 per pound for multiple flight bookings. Cargo is installed in a shorter version of the standard cargo containers, 30 feet long with the same 15-foot cross-section. Vulture is protecting the innovations involved in production of Condor by refusing to sell any units; the growing fleet is owned and operated by the company's SpaceFreight Division, which operates scheduled cargo and passenger service to major earth-orbit facilities, including the Foundation Society's orbiting space settlements. Service to smaller facilities is arranged on a charter basis. The company now offers a family of Condor vehicles, with up to 40,000 lbs. payload capability to LEO, and launch rates as low as \$400 per pound for preferred customers. Wingless versions built on-orbit at Bellevistat (through a cooperative agreement with the Foundation Society) provide service from orbital facilities to the lunar surface and other space destinations.

Given Vulture Aviation's unique experience with large-scale operations in the vicinity of Mars, the company's executives are confident of winning the Foundation Society's "Argonom" contract.



# REQUEST FOR PROPOSAL

15 November 2047

## "Argonom" Space Settlement Contract

### INTRODUCTION

This is a request by the Foundation Society for contractors to propose the design, development, construction, and operations planning of a Space Settlement Community on the surface of the planet Mars.

The need and requirements for the "Argonom" Space Settlement have been established through studies performed by the Foundation Society, and through experience gained during development and operations of our existing Space Settlement Communities.

### STATEMENT OF WORK

1. **Basic Requirements** - The contractor shall describe the design, development, and construction of the "Argonom" Space Settlement Community, and develop plans for operations and support required to maintain the community. The Society wishes to minimize operating costs as much as practicable. Anticipated problem areas and/or requirements for advancements in state-of-the-art technology must be identified in the proposal, with options for resolution.

2. **Facilities** - Argonom must accommodate a community of 12,500 full-time residents plus an additional transient population, not to exceed 600 at any time, of business and official visitors, guests of residents, and vacationers; some of the visitors will be scientists studying Mars, its environment, the effects of large-scale human habitation on that environment, and ecosystem(s) (if any). The design must enable use of natural light, and views of surrounding terrain.

2.1 Exterior design drawings must identify utilization of all volumes, must illustrate the local terrain and compatibility with it, and must clearly show dimensions of major structural components. The proposal must identify construction materials utilized for major structural components. The design and materials must be capable of retaining their functionality and appearance in the Martian environment, without requiring significant expenditures of settlement resources for maintenance and repair. The proposal shall specify safety considerations and system redundancies, including protection from radiation and debris penetration. It is expected that drawings of the exterior will at least include identification of locations for landing site(s), vehicle maintenance facilities and parking areas, cargo and resources storage and/or warehousing, public utilities, heavy industry, residential/commercial areas, and agriculture.

2.2 The Argonom design must specify utilization of interior space, with areas designated and drawings clearly labelled to show industrial, residential, commercial, agricultural, and other uses. The proposal must provide justifications for facility sizes and locations. At least one drawing must show the total interior area of the settlement, and the proposal must include maps to show utilization of all interior areas; such drawings must clearly show dimensions of areas designated for specific uses. Research areas must include a laboratory for study of Mars samples that may contain evidence of life, and must be quarantined for protection of Argonom's population.

3. **Operations** - The contractor shall describe provisions for all operations necessary to support the community, including conduct of businesses for external trade and accommodating incoming and outgoing vehicles--including spacecraft, surface vehicles, and aircraft.

3.1 The proposal shall identify a recommended location on the Martian surface, and the reasons for its selection. Explain how searches for evidence of life on Mars could be conducted from this location. The proposal shall identify the sources of materials and equipment that will be used in construction and operations--Earth, asteroids, existing on-orbit facilities, Earth's moon, Mars

itself, or elsewhere--and means and costs for transporting these materials to the Argonom location. The proposal is expected to describe the process required to construct the settlement, by showing the sequence in which major structural components will be assembled. The proposal should detail any special construction techniques or automation required to complete the settlement.

3.2 The proposed Argonom design shall include elements of basic infrastructure required to support the activities of the settlement's residents, including (but not limited to):

- food production,
- electrical power generation,
- internal and external communication systems,
- internal and Martian surface transportation systems,
- water management,
- household and industrial solid waste management,
- atmosphere/climate/weather control, and
- day/night cycle provisions.

The proposal must define transportation corridors and means of access throughout and between facilities, including designs of transportation vehicles proposed for use in and around the settlement. Drawings of facilities related to transportation systems must show their dimensions, either as the size of the "footprint" they occupy on a map, or their length/width/height. Operations planning must consider that supply lines for imports may be interrupted for up to six months.

3.3 The proposal must describe any existing or new on-orbit infrastructure required to sustain settlement operations (e.g., vehicles, satellite support, power plants, or other permanent installations). It is preferred that these requirements be shown in a chart or table. The Foundation Society does not intend to fund development of new vehicle(s) for transporting goods and personnel to the Martian surface, and/or for transporting construction materials from extraterrestrial/extramartian sources. The proposal shall, however, identify requirements for any new launch/landing, on-orbit, or Mars surface vehicles that will be needed during construction, occupation, and operations of Argonom, so that the Foundation Society can encourage commercial development of these vehicles.

4. **Human Factors** - Quality of life is an especially important consideration for Foundation Society members, who plan to maintain traditional comforts of Earth without the sacrifices normally associated with a frontier environment. Argonom must provide a safe and pleasant living and working environment for residents of its community(ies). Please bear in mind the traditional human factors that a wealthy resident of one of Earth's major cities might enjoy (e.g., large houses, fine food, access to world-class entertainment). Consider also that humans prefer natural sunlight, and part of the appeal of living on and visiting Mars is what can be seen there.

4.1 Argonom communities shall provide their residents with facilities for customary services (e.g., housing, education, entertainment, medical, parks and recreation, etc.), variety and quantity of consumables and other supplies, and public areas designed with open space and consideration of psychological factors. The proposal must depict or specify means of distributing consumables to Argonom residents. The proposal shall include maps and/or illustrations depicting community design and locations of amenities, with a distance scale. Medical facilities must be available for quarantine and treatment, if necessary, of people who may become exposed to Martian life forms.

4.2 The proposal shall include designs of typical residential accommodations, clearly showing room sizes. The full-time inhabitants will be Foundation Society members who are involved with development of facilities for further habitation of Mars, who operate business ventures in the settlement or elsewhere on Mars, who manage settlement maintenance and operations, and who produce products and services as needed by the community and for trade. Anticipated demographics of the original population are:

Married adults	58%
Single Men	21%
Single Women	17%
Children	4%

4.3 The proposal shall specify systems, devices, vehicles, and design characteristics as required to enhance productivity in the Mars environment (both inside and outside the settlement). Drawings of these items must clearly indicate their sizes. Argonom residents and visitors will expect to have "on demand" access to work, sightseeing, and recreation on the Martian surface.

5. **Automation** - Contractors' proposals must specify number and types of computers, software, network planning, and robotics applications required to support Argonom's facility and community operations. Show robot designs, clearly indicating their dimensions. Identify locations and sizes of support facilities and special transportation corridors for robots. Provide a chart that identifies all anticipated computer and robotics requirements in and around the settlement, and identifies the particular computers and robots that will meet each automation need.

5.1 Specify automation systems to sustain integrity of the settlement environment and infrastructure, including backup systems and contingency plans for failures. The proposal must define physical locations of computers and robots that support critical functions. Emphasize automation support to construction, development of infrastructure on Mars, maintenance, repair, and safety systems. Robots that operate outdoors must be capable of retaining their functionality and appearance in the Martian environment.

5.2 Specify automation systems to enhance livability in the community, productivity in work environments, and convenience in residences. Emphasize automation support to commercial, agriculture, and port operation activities. Use of automation to reduce requirements for manual labor is a high priority for the Foundation Society. Access to computer data bases and processing must be available to every resident at any time and any place in the community.

5.3 Robot systems required for emergency external repairs must be capable of accomplishing tasks and surviving during solar flare activity.

6. **Schedule and Cost** - The proposal shall include a schedule for development and occupation of Argonom, and costs for design through construction phases of the schedule.

6.1 The schedule must describe contractor tasks from the time of contract award (16 November 2047) until the customer assumes responsibility for operations of the completed settlement. Show in the schedule the dates when Foundation Society members may begin moving into their new homes, and when the entire original population will be established in the community.

6.2 Specify the costs associated with Argonom design through construction in U.S. dollars, without consideration for economic inflation.

6.2.1 Include estimates of numbers of employees associated with each phase of design and construction in the justification for contract costs to design and build Argonom. Show separate costs associated with the different phases of construction.

6.2.2 Describe costs that the Foundation Society will be expected to incur annually to operate the settlement, including:

- personnel,
- maintenance,
- supplies, and
- services;

these costs will not, however, be included in the Argonom contract.

7. **Business Development** - Argonom must be designed to accommodate a variety of commercial and industrial ventures. The settlement must include adequate provisions for commercial activities to enable economic self-sufficiency for on-going operations five years after initial full occupancy and operational capabilities are achieved. Trade will be conducted with Earth and other space facilities. The basic design must include sufficient flexibility to accommodate development of additional compatible business types with little configuration change. The original configuration must, however, accommodate three major business pursuits:

- **Infrastructure Development**
  - Argonom will serve as a staging area and headquarters for construction of roads and other facilities to service expanding operations on Mars
  - Long-distance surveying expeditions will be provisioned and serviced at Argonom
  - Construction crews, their equipment, and supplies will be routed through Argonom
- **Mining Operations**
  - Ores from potential mining sites will be assayed to determine commercial value
  - Mars materials will be extracted and prepared for transportation to users
  - Customers may require refining and/or separation of materials before delivery
  - Customers may request delivery of manufactured parts

- Hotel
  - Lodging and related facilities are required for up to 500 guests
  - Up to half of hotel guests are expected to be tourists
  - Proposals shall recommend anticipated numbers, demographics, stay times, and itineraries of tourists
  - Hotel facilities must be readily expandable if justified by customer demand
  - Touring and excursion services to Martian points of interest must be available for guests
- 8. **Special Studies** - Plans shall be included in the proposal for emergency procedures to react to two disaster scenarios:
  - Damage to an inhabited part of the facility due to meteorite or debris penetration, or collision by a vessel, including a 1.5 meter diameter hole that allows contained atmosphere to escape
    - Describe safing plan to isolate affected volume from other parts of the settlement
    - Describe provisions to maintain structural integrity during loss of atmosphere
    - Provide a schedule of tasks necessary to accomplish repair activities and resumption of full service in affected volume
  - Contamination of atmosphere in connected habitable areas due to explosion involving hazardous chemicals
    - Describe provisions for relocation of affected personnel and activities during clean-up
    - Schedule activities to return the settlement to full operation

### **ADDENDA**

Submitted proposals may suggest alternate names for this community, within the Foundation Society's established naming convention that requires the name to begin with the letter "A" and end with the suffix "om".

The proposal may suggest an alternate population for the settlement, if warranted to assure fulfillment of Argonom business objectives and maintenance requirements.

If a proposal is submitted that has more than the allowed 50 pages, only the first 50 pages will be provided to the judges.

Drawings and/or maps included in the proposal must show dimensions consistently in English (feet/miles) or metric (meters/kilometers) notation.

# **PRELIMINARY**

## **REQUEST FOR PROPOSAL**

**14 November 2047**

### **"Argonom" Space Settlement Contract**

#### **INTRODUCTION**

This is a request by the Foundation Society for contractors to propose the design, development, construction, and operations planning of a Space Settlement Community on the surface of the planet Mars.

#### **STATEMENT OF WORK**

1. **Basic Requirements** - The contractor shall describe the design, development, and construction of the "Argonom" Space Settlement Community, and develop plans for operations and support required to maintain the community.
2. **Facilities** - Argonom must accommodate a community of 12,500 full-time residents plus an additional transient population, not to exceed 600 at any time, of business and official visitors, guests of residents, and vacationers; some of the visitors will be scientists studying Mars, its environment, and ecosystem(s) (if any). Exterior design drawings must clearly show dimensions of major structural components. The Argonom design must specify utilization of interior space; drawings must clearly show dimensions of areas designated for specific uses.
3. **Operations** - The proposal shall identify a recommended location on the Martian surface, and the reasons for its selection. Explain how searches for evidence of life on Mars could be conducted from this location. The proposed Argonom design shall include elements of basic infrastructure required to support the activities of the settlement's residents, including food production, electrical power generation, communication systems, transportation systems, water management, household and industrial solid waste management, atmosphere/climate/weather control, and day/night cycle provisions.
4. **Human Factors** - Argonom communities shall provide their residents with facilities for customary services (e.g., housing, education, entertainment, medical, parks and recreation, etc.), variety and quantity of consumables and other supplies, and public areas designed with open space and consideration of psychological factors. The proposal shall include designs of typical residential accommodations, clearly showing room sizes.
5. **Automation** - Contractors' proposals must specify number and types of computers, software, network planning, and robotics applications required to support Argonom's facility and community operations. Show robot designs, clearly indicating their dimensions. Specify automation systems to sustain integrity of the settlement environment and infrastructure, including backup systems and contingency plans for failures. Specify automation systems to enhance livability in the community, productivity in work environments, and convenience in residences.
6. **Schedule and Cost** - The proposal shall include a schedule for development and occupation of Argonom, and costs for design through construction phases of the schedule.
7. **Business Development** - Argonom must be designed to accommodate a variety of commercial and industrial ventures. The original configuration must, however, accommodate three major business pursuits: Infrastructure Development, Mining Operations, and a Hotel.

## Appendix A: SUBCONTRACTORS

Major aerospace contractors and customers have access to a vast network of non-aerospace and smaller companies with relatively limited product lines. They are eager to make or do anything they are capable of making or doing, for anyone who will pay. They frequently have contracts with competitors for the same proposal. These include:

**BeamBuilders, Ltd.** is a European company which operates an automated manufacturing facility on a ferro-nickel asteroid that it has placed in orbit around the Earth-Sun L4 libration point. The company produces triangular trusses to customer-specified dimensions, at the rate of 600 linear feet per hour. Customers are required to provide their own transportation of these structures, although some limited assembly is permitted in the vicinity of this operation. The company's standard triangular truss with 12-foot sections, suitable for zero-g installations, typically sells for \$1000 per linear foot. Custom orders are more expensive.

**Efficient Software, Inc.** was founded by four Bellevistat engineers who recognized that people making their homes in space have some incentives for not wanting to constantly expand their computer systems to accommodate increasingly complex and memory-hogging software. The company is licensed by major software producers to convert popular new programs into more-efficient versions that are compatible with files prepared using the original software, but require less memory, bandwidth, and other resources. The company's products have also become popular among some segments of the dirtside public. Efficient Software avoids a quagmire of lawsuits by paying licensing fees to the original software suppliers.

**Fusion Founders** serendipitously happened upon an apparently ideal combination of conditions and equipment to produce practical fusion power in 2013. The company has been busily producing power plants since that time, at its manufacturing facility in Yukon Territory. Although it can assemble large municipal power plants at customer-specified sites, its most popular product is a self-contained unit that can be shipped on a modified commercial version of a C-19 transport aircraft, and installed by local labor with supervision provided by a company engineer. The unit, weighing 200,000 pounds, includes a 17-foot diameter sphere, its 80-foot-long cooling "barn", and a support "shed". The system is shipped pre-assembled, and generates 10 MW, appropriate for non-industrial communities of about 5000 people. Fusion Founders has received several solicitations to develop a version of this unit that could be launched into space, but feels that it has achieved the theoretical limit of smallness for a fusion reactor. The company has offered to attempt to develop such a reactor if it is paid a \$10 billion fee, but will not guarantee success.

**Heavenly Jitneys** provides regular but unscheduled transportation services between locations in Earth orbit, including all space stations, settlements, and major commercial sites. The service was started by a pair of Alexandriat residents using vehicles built at Bellevistat for the company's fleet, which is based at Columbiat. Although primarily a service for passengers and their luggage, the company can haul some cargo either in small packages that fit in the passenger compartments, or secured to a 10 by 15 foot flat surface on the "bottom" of each vehicle. Rates average \$10,000 per person per day of travel, and \$50 per pound of cargo per day of travel.

**Litigation Limiters** is a law firm that founded a niche market which virtually eliminates conflict-of-interest suits for its clients, who usually are companies competing for the same contracts but in need of each others' products and/or services. Litigation Limiters arranges its own contracts between providers of products and services, and customers, then serves as a go-between to supply the products and services to the customers. The company has such agreements with all of the world's diversified corporations that have significant product lines applicable to space development. Litigation Limiters charges a 2% fee on product or service value.

**Lossless Airlocks** is a Bellevistat manufacturer that has developed and sells airlocks that operate with almost no loss of atmosphere for each opening to space. Airlocks come in several sizes, including a single-person unit, and a personnel transfer system that can simultaneously

accommodate ten people in adjacent chambers; the largest is an equipment transfer chamber designed for standard space cargo containers (15 feet square by 45 feet long). The system is somewhat disconcerting for people to use; when outgoing, a coated kevlar tube envelops the occupant, who is then ejected rather forcefully when the outer doors are opened. It has, however, enabled retention of precious air in all sizes of vehicles, and is an important asset for preservation of the fragile indigenous lunar atmosphere. In response to some serious problems with soil contamination of machinery in lunar bases, the company has been attempting to develop an airlock that will clean astronauts' suits as they enter controlled environments; the fine-grained, sharp-edged, electrostatically-charged lunar dust has, however, resisted all attempts to control it.

**Lunar Adventures** is an Alaskol-based operation that provides spacesuits and guide-operated vehicles for excursions on the lunar surface. The vehicles provide a shirtsleeve environment for six passengers plus the guide, and accommodations for overnight "camping". The electric-powered vehicles can be self-sufficient for up to a week in sunlight with storage for two days of power in darkness, and have a range of 200 miles per day. Passengers are charged \$1000 per person per day, or \$5000 per day for charter of a vehicle and guide. Spacesuit rentals are \$150 per day.

**OrbitLink Communications** was established when the Alexandriat Space Settlement was under construction, to augment standard communications channels. Individuals who insist on transmitting and receiving data-hogging video and interactive real-time data with Earth-based services do so by paying exorbitant fees to OrbitLink. The company has made arrangements to place one of its antennas and dedicated fiber optics links on every Foundation Society settlement.

**Tanks-A-Million** is a Belvestat-based manufacturer that uses lunar materials to build tanks for all applications on spacecraft. The company has facilities that can make nearly perfectly round tank cross-sections to any size between one foot diameter spheres and 18 foot diameter by 50 foot long cylinders. Tanks can be specified for high pressure, cryogenic, or fuel applications, and feature an extraordinarily reliable system for keeping contents at the exit points in zero g. The company claims that its zero-g manufacturing techniques reduce flaws and "corners" that can serve as starting points for stress fractures in pressurized tanks.

**Totally Remote Ultimate Escapeways / Guest Requested Innerpeace Treks (TRUE/GRIT)** offers the ultimate get-away-from-it-all vacation. Guests enjoy luxuriously-appointed small spacecraft which can accommodate up to four people for two weeks. The company delivers each spacecraft and its guest(s) to an orbit with no hazards from known debris, where it remains either until its occupants request retrieval or supplies are nearly depleted. Privacy is guaranteed, although critical vehicle systems, oxygen depletion, and temperature are monitored to assure that occupants are not in difficulty. Guests may change the attitude of the vehicle for different views, but have no ability to change orbits. Rates are \$9000 per person per day, or \$30,000 per day for charter of a spacecraft. Extravehicular Activity (EVA) experiences are offered for \$1000 extra per person per trip. These zero-g escapes are highly favored by designers, authors, and artists who seek creative inspiration.

**ZAP! Industries** is the leading supplier of wire harnesses and fiber optics systems for distribution of electrical power and electronic signals on spacecraft. In 2025, the company completed development of a system for zero-g manufacturing of solar cells from materials available in silicate asteroids. ZAP! sells each of these units for \$40 million, not including transportation to deposit it on an appropriate asteroid, where it produces 1 x 2 foot solar panels at the rate of 10,000 per day, each of which is capable of generating 40 watts of power in Earth orbit and weighs 2 pounds, at a cost of \$40 per kW (not including transportation to the use site).

## Appendix B: Space Settlement Design Competition GLOSSARY

Many of the words and terms used in Space Settlement Design Competitions materials are not part of familiar everyday usage:

**air-breathing engine:** a propulsion plant (motor) that acquires oxidizer from the air, rather than carrying it in tanks on the vehicle (as required by rocket engines)

**airlock:** a chamber that enables people and things to move or be moved between volumes with different pressures; like a lock in a canal, the chamber starts at the pressure that the occupant is moving from, and changes to the pressure being moved to

**attitude (of a vehicle):** a vehicle's orientation relative to Earth, Sun, or other objects; typically used to describe a desired view, observation target, or heating environment (e.g., a "sun-facing" attitude assures that one side of the vehicle will always be hot, and the other side always cool)

**avionics:** literally, "aviation electronics", mostly including commanding and monitoring of systems on aircraft and spacecraft

**cargo:** the reason a vehicle flies; stuff that is carried by a vehicle from its starting point (ground or on-orbit) to the vehicle's destination; can include satellites, bulk materials, construction components, or people

**cargo container:** a standard carrier in which cargo is carried for a mission; ideally, all spacecraft cargo is containerized, because complex installations and interfaces can be accomplished to the inside of the container, and the standardized exterior interfaces of the container can be quickly mated to the inside of a cargo vehicle (standardized containers have been used for decades on ships, conventional aircraft, railroad cars, and trucks)

**consumables:** stuff that is used up during the course of a mission or over a period of time, and hence must be replaced; includes everything from rocket fuel to pet food to pencils

**contract:** a legal agreement between a customer and a company (contractor), whereby the contractor agrees build something or provide a service within a defined cost and schedule, and the customer agrees to pay the cost when the product is delivered (contracts may have provisions for partial payments over the course of a long product delivery schedule)

**dirtside:** of or referring to Earth, people living there, and things on it

**down area:** in a rotating space structure, the interior surfaces through which the force due to the rotation ("artificial gravity") appears to be vertical; conversely, surfaces inside a rotating space structure on which a person could stand or things could be placed, as if they were on the ground

**Expendable Launch Vehicle (ELV):** a launch vehicle which is used for only one launch; typically, it sheds some of its components, or stages, during the launch process, with only a small portion of the original "stack" being delivered all the way to orbit

**Extravehicular Activity (EVA):** an excursion by a person in a spacesuit outside of any vehicle or habitat

**fabrication:** manufacture; the process of making, building, and/or assembling

**GEO:** geosynchronous Earth orbit; objects in 22,300 mile orbits rotate around the Earth at the same rate that the Earth turns on its axis; when located above the Equator, these objects appear to be stationary in Earth's sky



**fiber optics:** use of tiny, transparent strands to transmit light that represents electronic signals; can replace traditional copper wire with less weight and expense, and greater reliability, but is not capable of transmitting power

**hypersonic flight:** flight through an atmosphere at greater than five times the speed of sound (Mach 5) for that atmosphere

**Lagrangian points:** (see "libration points")

**launch vehicle:** a spacecraft that is capable of launching or flying through an atmosphere (e.g., Earth's) in order to get into space and achieve orbit

**LEO:** low Earth orbit; orbital locations above Earth's atmosphere and below the Van Allen radiation belts

**libration points:** in orbital mechanics, when one large body (e.g., the Moon) is in orbit around another large body (e.g., Earth), there are five points in orbits around the larger body where gravitational forces balance out to enable satellites to be placed where they could not stay if the smaller of the large bodies were not present (also called Lagrangian points, for Joseph Lagrange, the mathematician who developed the theory that predicts their existence)

**low-g:** acceleration environment with less than the acceleration due to gravity on Earth's surface

**mass driver:** a device that electromagnetically accelerates small objects to very high velocities; can be utilized for efficiently launching material from airless surfaces

**micro-g:** an accurate description of "weightlessness", the condition experienced in space when forces balance out and objects seem to "float"; true "zero-g" is theoretically not possible, because there are always some tiny forces operating on all objects

**on-orbit:** in space, in an orbit; usually refers to an orbit around Earth

**orbit:** the path assumed by an object in space, due to balancing or "cancelling out" of accelerations due to gravity and rotation; usually the elliptical path of a small body (e.g., satellite) around a very large body (e.g., planet, moon, or star)

**overhead:** the part of a budget that does not show up as part of the cost of work directly on a project, but is charged to the customer as part of the hourly charge for direct work (i.e., a contractor is paid for each hour an engineer works on tasks directly related to the project; the customer is billed a cost for the engineer's hours that is greater than the salary paid to the engineer; the difference pays for computers, upkeep of the facility, janitors, utilities, secretaries, and other costs required to support the engineer's work)

**payload:** literally, "paying load"; cargo carried by a vehicle, for which a fee is being paid in exchange for moving the cargo to its destination

**payload capability:** weight of payload(s) that a launch vehicle is capable of carrying to orbit

**payload integration:** the process of safely stowing a payload (usually a satellite or complex device) on a launch vehicle and providing services (often including electrical power, avionics, and thermal control) that enable the payload to survive the flight and accomplish its purpose; includes design of payload services, analysis of payload's ability to survive environments it will experience, and installation in the vehicle

**profit:** the difference between the price charged by a contractor for providing a product, and the actual cost the contractor incurs to make the product

**proposal:** a document prepared by a company or other entity, in order to convince a customer to select the company as the contractor that will provide a certain product; it describes the company's recommendation for how it could provide the product, and explains why the customer should have confidence that the company has a superior design and can be relied upon to produce it according to the customer's requirements and within the described cost and schedule

**Request for Proposal (RFP):** a document prepared by a customer, which describes features of a product they want a contractor to produce

**requirements:** features that a customer requests to be included in the design of a desired product

**Reusable Launch Vehicle (RLV):** a launch vehicle that returns from its missions intact, and is designed to be maintained after flight and fly repeated missions

**satellite:** any object in orbit around another object; usually refers to human-made devices in orbit around large natural bodies (i.e., planets, moons, stars)

**shirtsleeve:** an environment inside a vehicle or habitat that enables humans to operate without protective clothing

**Single Stage to Orbit (SSTO):** the capability of a launch vehicle to accomplish a mission from the ground to orbit without staging, or shedding of components during the launch process; such vehicles contain all of the fuels and oxidizer they require in tanks inside their structures, and return to the ground with the tanks intact (the amount of oxidizer required can be reduced through use of air-breathing engines during flight in the atmosphere)

**solar panel:** a device that converts sunlight into electrical power

**Solar Power Satellite:** a satellite, usually very large, consisting mostly of large arrays of solar panels producing electrical power that can be converted (usually to microwave energy) and transmitted to users in other locations

**solar sail:** a surface, usually very large and lightweight, that makes use of pressure due to light or solar wind for propulsion

**spacer:** of or referring to people who live in space

**spacesuit:** a garment that provides pressure, breathing air, fluids and nutrients, waste removal, and protection against the space environment, and that enables a human to move and operate in the space environment

**SSTO:** see "Single Stage to Orbit"

**Van Allen radiation belts:** bands of radiation trapped in Earth's magnetic field, which both absorb ambient deep-space radiation and provide protection for Earth's surface, and are a hazard for satellites and humans operating within them

**zero-g:** see "micro-g"

1997

**Victor Valley Space Settlement Design Competition  
SCHEDULE OF EVENTS**

**Friday 14 November**

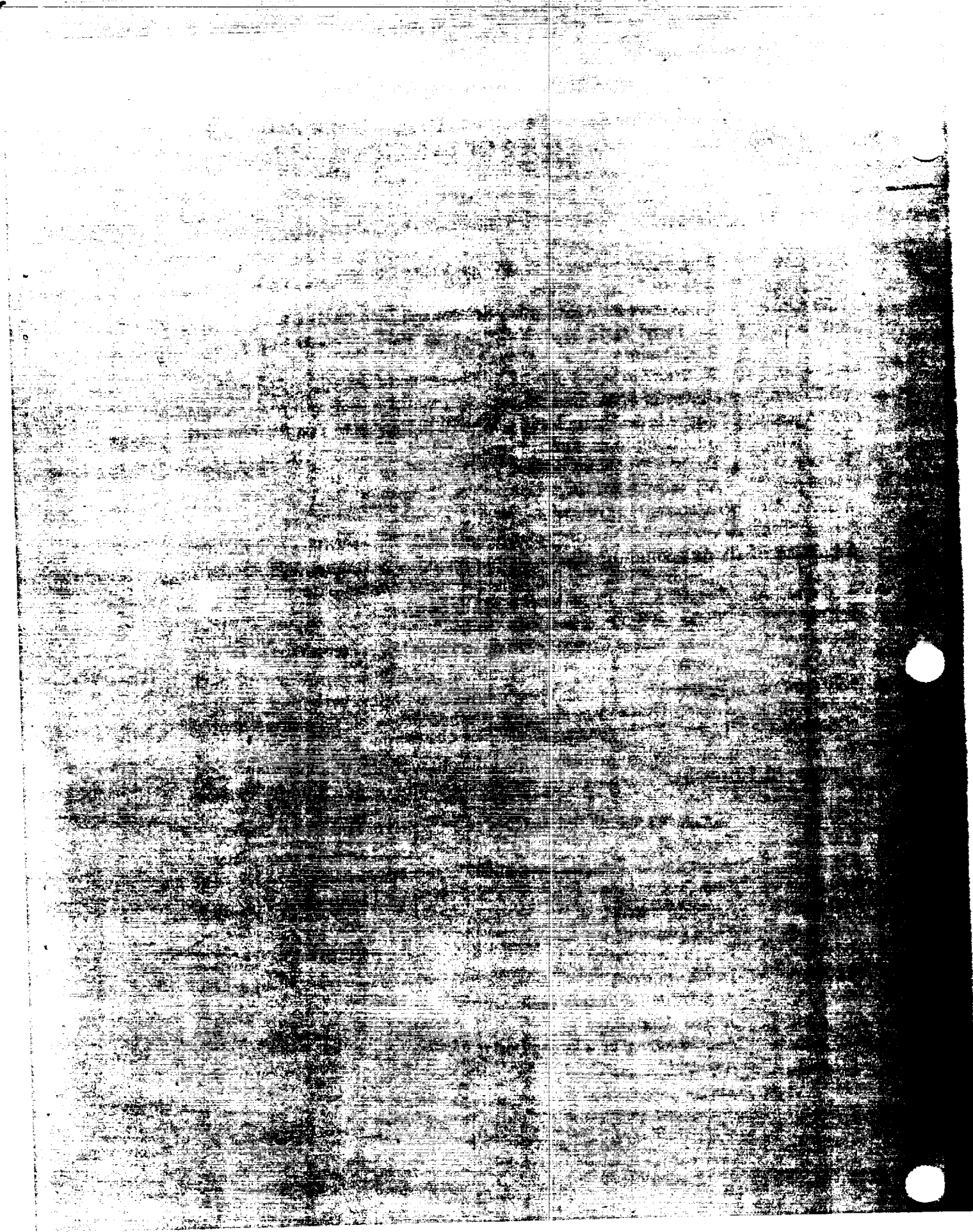
5:00 p.m.	Registration and check-in at Victor Valley College
6:00 p.m.	Software Demonstration
7:30 p.m.	Buses leave for Apple Valley Science and Technology Center
8:00 p.m.	Star Party! at the Apple Valley Science and Technology Center
9:15 p.m.	Buses return to Victor Valley College
9:45 p.m.	Welcome on behalf of NASA, Dryden and Competition Sponsors
10:00 p.m.	History of Space Settlements
10:15 p.m.	You're in the Future Now! — What Will Happen to You this Weekend
10:30 p.m.	How Companies Work
10:45 p.m.	You're a Professional Now!
11:00 p.m.	Assignments to Design Competition Companies
12:00 midnt	Lights out! in gymnasium sleeping quarters

**Saturday 15 November**

8:00 a.m.	Breakfast and Teams meet with CEO's
9:00 a.m.	Technical Training Sessions
10:30 a.m.	Teams meet in Company Headquarters to Begin Preparation of Designs
12:00 noon	Lunch
6:00 p.m.	Dinner
11:00 p.m.	Library closes
12:00 midnt	Lights out! in gymnasium sleeping quarters

**Sunday 16 November**

7:30 a.m.	Companies submit finished Design Proposals to Foundation Society
7:30 a.m.	Breakfast
8:30 a.m.	Assemble for Design Presentations
8:40 a.m.	First Presentation
9:30 a.m.	Second Presentation
10:20 a.m.	Third Presentation
11:10 a.m.	Fourth Presentation
12:00 noon	Lunch
1:00 p.m.	Activity during Judges' deliberations
3:00 p.m.	Judges' debriefing
3:30 p.m.	Announcement of Winning Design
4:00 p.m.	Adjourn



## Introductory Information

Information and resources that will be accessible for you during the Space Settlement Design Competition include a library of books available to be checked out, and copies of articles from technical journals and other publications.

All books and articles utilized in Space Settlement Design Competitions have been assigned unique catalog numbers to aid participants in finding information they need. Assigned catalog numbers indicate the *primary* area of applicability, although it is possible and indeed likely that many books and some articles will have information useful in other areas as well.

This package includes copies of articles that are considered to be of general interest to all participants. The next page lists these articles; the notation "ALL": in the "Dryden 97" column indicates articles that are included here. The notation "bound" indicates articles included in a volume of "Supplementary Information" that will be provided to each company during the Management Session.

Additional articles will be provided in Technical Sessions and the Management Session on Saturday morning.



# Dryden 97 Articles

CODE	Dryden 97	ARTICLE NAME
		Articles of general interest:
G203	bound	Making a Home in Space
G293	ALL	The Wild Blue Ponder (Dryden Flight Research Center)
G294	ALL	The Outer Limits (Dryden Flight Research Center)
G202-M	ALL	Mars Vision
G206-M	ALL	The Case for Colonizing Mars
G207-M	ALL	The Significance of the Martian Frontier
G208-M	bound	The Challenge of Mars
G220-M	ALL	The Once and Future Planet
G225-M	ALL	Is Mars Alive?
G280-M	ALL	A Colony in the Sky
G320-M	bound	Digging Deeper for Life on Mars
G322-M	ALL	Martians Wanted: Dead or Alive!
G380-M	ALL	Can a Dead World Be Brought to Life?
G383-M	bound	Terraforming - Greening the Red Planet
G420-M	ALL	Basic Mars Information
G421-M	ALL	A Coolness on Mars
G422-M	ALL	Mars: Just the Facts





## The Wild Blue Ponder

Tests at Dryden Flight Research Center Have Aided Aviation for 50 Years

By DAVID COLKER  
TIMES STAFF WRITER

**E**DWARDS AIR FORCE BASE—The most famous person ever associated with the NASA Dryden Flight Research Center, which is about to mark its 50th birthday, will probably not be invited to speak on its behalf any time soon.

Chuck Yeager broke the sound barrier here in 1947, but he's made no secret of his belief that cautious government officials with NASA's precursor—the National Advisory Committee for Aeronautics—delayed the project unreasonably.

"NACA did not contribute a hell of a lot," said the retired Air Force general, speaking last week from his home in Northern California. "They only reduced the data for us."

Yeager acknowledged in his bestselling autobiography, however, that data the committee collected in its 10-pound payload on the X-1—the rocket-powered craft with which he made history—provided invaluable feedback.

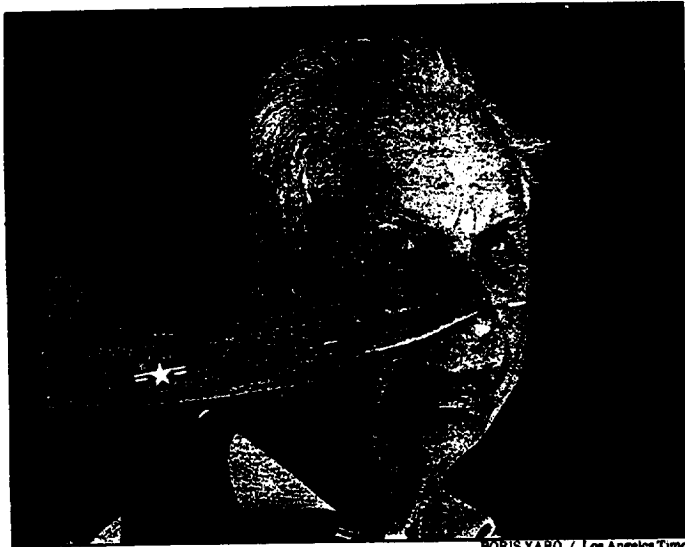
That was the job of NACA, as it is now of NASA, at the Dryden center, which in characteristic, low-profile style plans no public commemorations of its golden anniversary. Gathering data for basic research may not be the sexiest part of aviation, but it has played a vital role in landmark projects at the center, beginning with the X-1 and including the legendary X-15—which flew at six times the speed of sound—the lunar landing vehicle and the space shuttle.

These days, engineers, programmers and pilots at Dryden are conducting research on projects including systems that could be used on civilian supersonic jets, and high-altitude pilotless aircraft that would have the ability to stay aloft for several days at a time.

It was announced this year that Dryden will be the primary testing site for the X-33, a prototype for the next generation of reusable spacecraft.

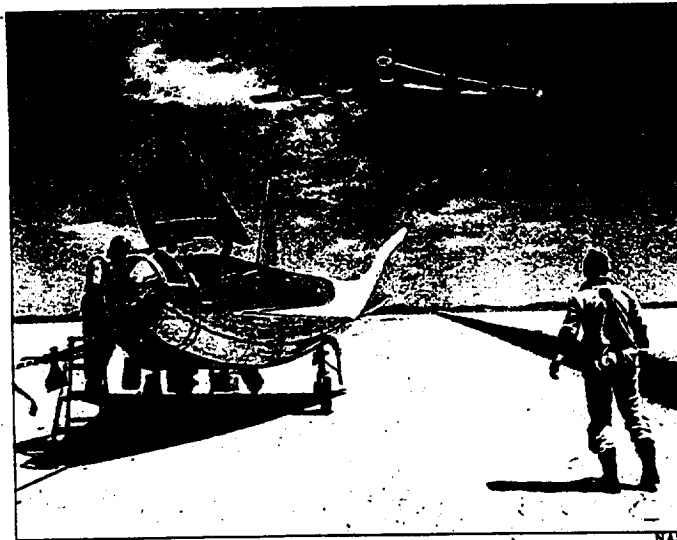
Dryden has had its ups and downs over the decades, but the need for basic research seems unending.

"There is a lot we still don't know about aerodynamics," said Dryden spokesman J.D. Hunley, "even though we have been doing it for almost a century."



BORIS YARO / Los Angeles Times

Don Borchers with a model of the X-1 aircraft, which was the first to break the sound barrier. Below, aircraft on dry lake bed at Edwards in 1969.



NASA

The remote, high-desert air base that is home to Dryden was not the first choice for a national flight test center. Before World War II, most of this work was done at Wright Field

near Dayton, Ohio, according to "On the Frontier," a NASA-sponsored history of Dryden by Richard Hallion.

But Wright was too close to residential areas to allow for hazardous

test flights, and the Army, which ran most of the testing then, wanted a more private locale where secret aircraft could be put through their paces. Officials also wanted a place with better year-round flying weather than Ohio.

NACA did early test flights of the X-1 at Pinecastle Field in Orlando, Fla., but "they didn't have clear enough conditions," Hunley said. "They wanted open skies so that they could monitor flights at all times."

In the fall of 1946, the X-1 team arrived at Muroc Army Air Field, which became known as Edwards Air Force Base in 1950. Yeager had been there in 1945. "For a pilot, it was a godsend," he said.

"You couldn't ask for better weather, clearer skies most of the time, plenty of room. It's a dream place."

At the heart of Edwards is the largest dry lake bed in the world, a 44-square-mile area now known as Rogers Lake. Dry lakes are not only the flattest of all land forms, they also have an extremely hard surface, making them ideal natural runways.

Edwards does get high winds, but they generally come from one direction. "It's a predictable element," Hunley said, "so that is OK for aviation."

The crew chief on the X-1, Jack Russell, who had come from Buffalo, N.Y., loved more than the area's good flying conditions. "I had had enough of that Buffalo snow," recalled Russell, who was working at the time for the Bell aircraft company, which manufactured the X-1.

The fact that temperatures on the dry lake bed can hit 115 degrees in summer didn't faze him. And these were the days before air-conditioning.

"The dry heat didn't bother me," said Russell, who retired 17 years ago and lives in nearby Lancaster. "I thought I had died and gone to heaven."

Others believed they had gone in the other direction.

"There was a story about an engineer," said Betty Love, who began work at the flight test center in 1952 compiling test data. "He signed in at administration, got his desk, and an hour later he was gone."

The engineer, who had come to Muroc from Virginia, found the re-

Please see DRYDEN, A17

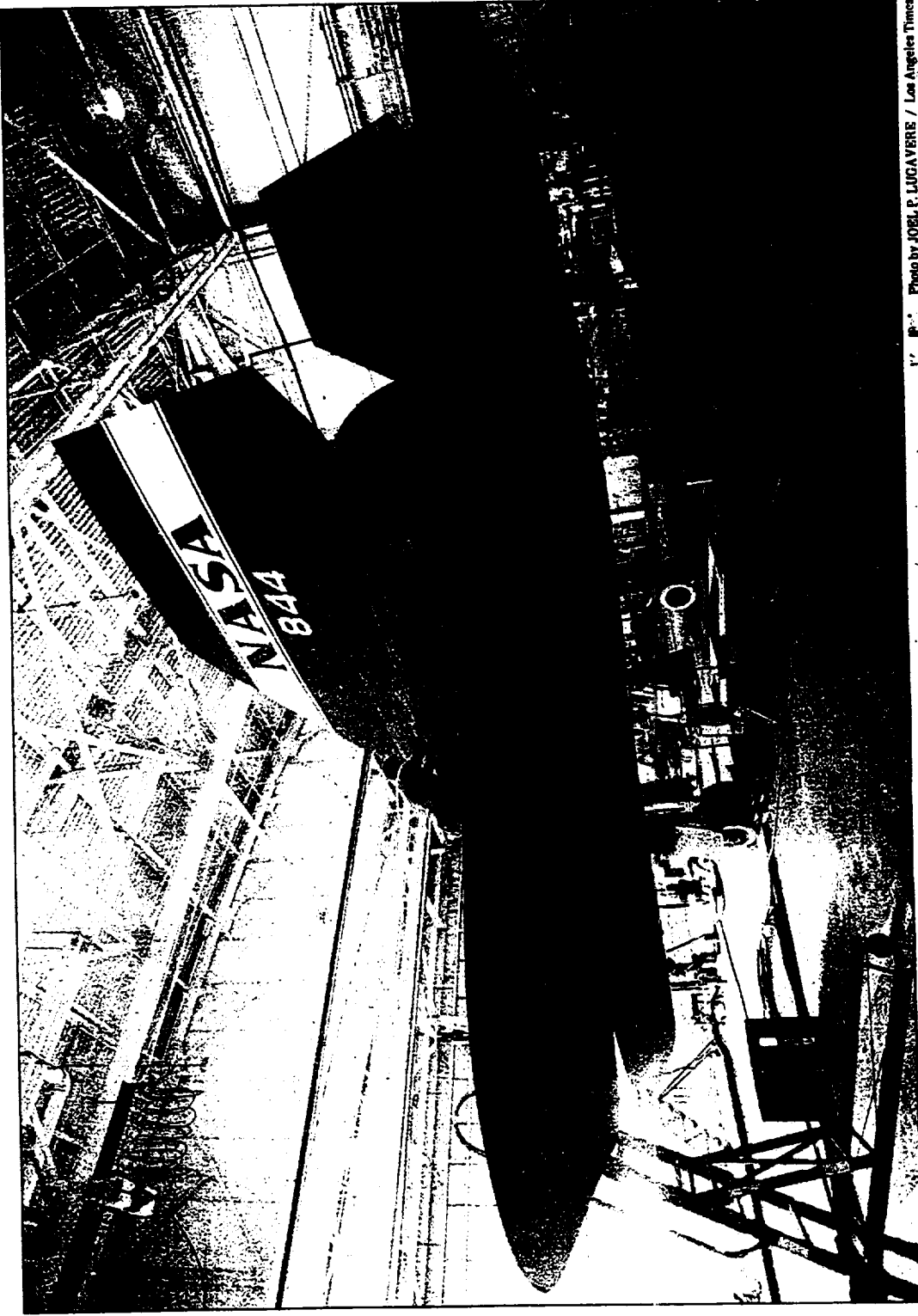


Photo by JOEL P. LUGAVERE / Los Angeles Times

Among the aircraft stationed at the Dryden Flight Research Center is the SR-71 Blackbird, which once flew coast to coast in 68 minutes, 17 seconds.

# DRYDEN

Continued from A3

mote, Mojave Desert landscape unnerving.

"It was pretty desolate compared to what they had come from in the East," said Love, who grew up in the area and was used to it.

Yet the center grew and officially became known as the Muroc Flight Test Unit in the summer of 1947. Yeager's breaking through the sound barrier on Oct. 14, 1947, still reigns as its most significant flight. In 1954, the testing unit left its hangars and buildings on what is known as Edwards' South Base, and moved northward to build its own facilities on the east side of the lake bed. The flight research center was still a tenant of the base but is now a more independent operation.

For many who worked there, it was a great time in their lives, even though conditions could be difficult. Swamp coolers, which made everything damp, were the only devices available to cool interior work spaces. Sandstorms were a frequent nuisance, and grit got into everything.

But the worst times were when a pilot died during a test accident. "The only way we could get data was sacrificing lives," Yeager said. "It's that blunt."

Many streets on the base are named for test pilots killed in crashes. One, in the Dryden complex, is Lilly Avenue.

"It was a family atmosphere in

the old days," said Don Borchers, who started there in 1947 and was crew chief of an X-1. "Everyone knew everyone. Everyone loved Howard Lilly."

In May 1948, Lilly was flying a D-559-1, better known as a Sky-streak, when the rocket-powered engine broke up shortly after take-off and the aircraft plunged into the lake bed and exploded.

The accident was caused by engine failure, and the crew was not to blame. But Borchers, who was chief inspector of the unit, took it hard.

"I had to leave. I was devastated," said Borchers, now 74 and living in Lancaster. He eventually went to work for the Postal Service and retired in 1977.

The center was named in 1976 for the late Hugh L. Dryden, a pioneering aeronautical scientist who was the highest-ranking NACA official at the time of Yeager's historic flight.

The current staff includes about 450 full-time government employees and an equal number of contract workers. The budget for fiscal '95 totaled about \$240 million.

Among the aircraft now used for tests at the center is the SR-71, the famed Blackbird spy plane that once flew from Los Angeles to Washington, D.C., in 68 minutes, 17 seconds.

Instead of slide rules, employees now use computers. Because of highly advanced simulators, flight testing is more predictable. And all the buildings are air-conditioned.

But some veterans miss the old

days. For women, for instance, the center offered a rare chance to break into new fields.

"I was going to go to nursing school but then like most young girls at the time, I got sidetracked by marriage and a family," Love said.

A friend told her jobs were available at the flight research center. She became what was known as a "computer."

The job extracting and analyzing information from test instruments required spending long hours over a small light box, measuring marks made during a flight on film. "You would get maybe 12 to 16 rolls of film from a test flight," said Love, now 74 and a resident of Lancaster. "They would tell you the speed, altitude, acceleration."

All the "computers" in the days before electronic calculators and digital readouts were women. Love admitted the work was repetitious and at times tedious.

"I imagine a man would get very tired of that," she said.

But it gave her the chance to be a part of an exciting endeavor, and eventually she advanced to become an aeronautical engineering technician. She worked at the center for 25 years, until she retired.

"I just feel real blessed I got to be part of it," she said. "Reading the pilot notes, checking the test results. I was fascinated by everything."

The Dryden history, "On the Frontier," is available at no cost on a NASA World Wide Web site on the Internet (<http://www.dfr.nasa.gov/History/Publications/SP-4303>)



SECTION

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MONDAY

JULY 21, 1997

## BUSINESS

ORANGE COUNTY  
Los Angeles Times

## THE CUTTING EDGE

## The Outer Limits

■ **Aerospace:** After 51 years, NASA's Dryden Center still pushes the physical—and economic—envelope of flight.

By KAREN KAPLAN  
TIMES STAFF WRITER

EDWARDS AIR FORCE BASE

On Independence Day, the Pathfinder spacecraft landed in an ancient flood plain and introduced earthlings to the rocky red surface of Mars.

The \$250-million interplanetary project also served to introduce Americans to a new NASA—a space agency concerned not only with the Big Bang but also with attaining the biggest bang for its buck.

But that was old news to the folks at Dryden Flight Research Center, where engineers are designing and testing some of the country's most cutting-edge flying machines. This outpost of the National Aeronautics and Space Administration on the southwestern edge of the Mojave Desert is thriving on the kinds of "faster-better-cheaper" projects championed by NASA administrator Dan Goldin.

Although NASA's budget has shrunk nearly 10% since 1991, Dryden is the only one of the agency's nine centers experiencing substantial growth. With a comparatively trim annual budget of \$154 million, Dryden's corps of engineers is carrying out nearly 30 projects, many of them in cooperation with private companies. In fact, the goal is for much of the technology being tested here to reach fruition as part of the commercial aerospace industry.

In its 51 years, Dryden has made a name for itself by pioneering supersonic flight, creating the first planes with voice-activated controls and developing the digital fly-by-wire flight control systems that now substitute for mechanical controls in most military planes and some commercial aircraft.

Today, even though it behaves more like a business and less like a government lab, Dryden is still churning out high-tech airplanes and spaceships. This month it will begin preliminary flight tests on a

Please see DRYDEN, D14

## Less Is More

Falling budgets have forced NASA to rework itself into an agency that conducts "faster-better-cheaper" missions. Dryden Flight Research Center has taken that message to heart by conducting research in cooperation with a host of private companies.



## Dryden's High-Flying Projects

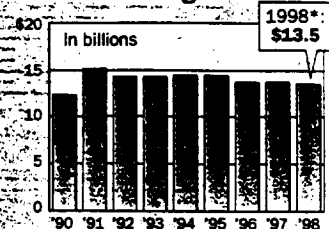
Dryden engineers will begin testing the X-38 crew-return vehicle, above, later this month. Construction of the first models of the Hyper-X hypersonic airplane, below, will begin in a few months. Flight tests will be monitored from Dryden's main control room, at right.



NASA

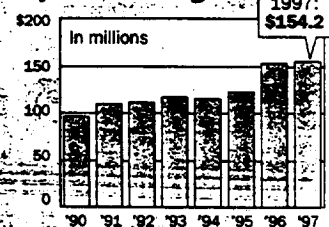
Sources: NASA, Dryden Flight Research Center

## NASA Total Budget

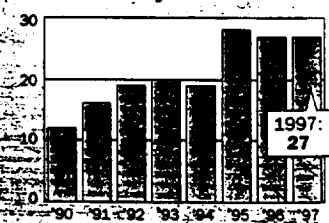


\*Requested; first decision has not yet been made.

## Dryden Total Budget



## Number of Dryden Missions



BORIS YARO/Los Angeles Times

# DRYDEN: On the Cutting Edge of Aerospace

Continued from D1  
vehicle known as the X-38, designed to return astronauts to Earth from the International Space Station—which will begin to take shape in orbit next year—in the event of an emergency.

The windowless fiberglass vehicle—which, with its white paint and black heat-absorbing tiles, bears a strong resemblance to famed killer whale Shamu—can hold six astronauts and ferry them to land on autopilot in about eight hours.

"They get in, close the hatch and separate from the station," said Chris Nagy, Dryden's chief engineer on the project. "Then the computer takes over and guides them into orbit."

The X-38 will circle the Earth once or twice before using a rocket to turn around, slow down and sink into the atmosphere. The computer system that runs the vehicle will use data from global-positioning satellites to guide it to one of six designated landing sites.

A series of parachutes will slow the X-38's descent to about 35 miles per hour and allow the computer to steer it to a runway. The 14,000-pound craft will slide to a stop on three ski-like skids. Eventually, the computer will be accurate enough to land the X-38 on a football field, Nagy said.

NASA economized on the X-38 by using the shape of an experimental vehicle from the early 1970s that had already endured detailed aerodynamic and heating tests. Although NASA provided the specs for the X-38's shape and main flight systems, the agency left it to engineers at Scaled Com-

posites of Mojave to design the mechanical systems that control the vehicle's parachutes.

The specialized design work was done while the vehicles were under construction, allowing Scaled Composites to complete the project in only eight months, said Chuck Richey, the company's X-38 project engineer. With a budget in the neighborhood of \$80 million over four years, the X-38's cost was "very little by aerospace standards," said Bob Williams, Scaled Composites' X-38 program manager.

"This was a milestone for working with a government agency as far as flexibility and the ability to make decisions and get the job done," Richey said.

Another example of Dryden's combination of high technology and down-to-earth business sense is the Hyper-X, an unmanned, wingless plane that will test the boundaries of supersonic flight 100,000 feet up. Paul Reukauf, chief engineer for the Hyper-X project at Dryden, envisions supersonic planes as big as Boeing 747s that can carry passengers on transglobal flights in just a few hours as well as smaller, more maneuverable military models.

As part of the five-year, \$155-million program, Dryden will test four Hyper-X planes built to fly between five and 10 times the speed of sound—about 3,375 to 6,750 mph, depending on atmospheric conditions. By comparison, the Air Force's fastest SR-71 Blackbird cruises at a mere 2,000 mph.

Hyper-sonic airplanes have been on drawing boards since the 1960s, but the technology required to

propel them has come of age only recently. Aircraft engines normally burn a mixture of fuel and oxygen in much the same way a typical automobile engine does. But at altitudes of 100,000 feet, the atmosphere is so thin that oxygen is hard to come by.

Military planes get around this problem by carrying an oxidizer (a component that mixes with fuel to make it combustible), but the extra weight is a hindrance. NASA engineers expect the Hyper-X to get the oxygen it needs from the thin air of the upper atmosphere. If the plane flies fast enough, they figure, it will pass through enough air to collect the needed amount of oxygen.

The Hyper-X will compress that oxygen by harnessing the power of the shock waves that are a by-product of breaking the sound barrier. The underbelly of the plane—a sleek, aluminum structure that resembles a surfboard with twin tail fins—was designed with a series of precise curves to compress air to about 95 times its original density.

The rectangular copper alloy engine beneath the Hyper-X's midsection will run on pure hydrogen, the most potent fuel around. After the hydrogen mixes with the compressed oxygen and burns, the pressure from the expanding gas will propel the plane forward.

To reach its cruising altitude, the Hyper-X will be attached to a rocket booster and ferried at least 18,000 feet high under the wing of a B-52. Then the rocket will be released to carry the Hyper-X nearly 20 miles above ground.

Much of the Hyper-X's design was taken from designs for the

National Aerospace Plane, a 1980s project to build an aircraft that could take off on a runway and fly all the way into orbit. The project fizzled a few years ago after consuming more than \$12.5 billion, but NASA is profiting from it now.

"This is a very refreshing program," said Lowell Keel, Hyper-X project manager at Micro Craft, the company that will build the models in Ontario and at the company's headquarters in Tullahoma, Tenn. "They have created a program that's doable and affordable."

Keel said construction of the first Hyper-X model will begin in a few months, and three more planes are to follow. Boeing Co.'s advanced programs group in Seal Beach is working on the plane's overall design and its flight control and thermal protection systems. The first Hyper-X is expected to arrive at Dryden in April, with its first flight scheduled for January 1999.

After that, Thad Sandford, vice president for research engineering and advanced programs at Boeing, expects the Hyper-X will evolve into an unmanned supersonic platform for communications, spy missions and military weapons. Fifteen years hence, larger versions of the Hyper-X could be used for high-speed cargo delivery, commercial travel and delivering satellites into orbit, he said.

"This will be a breakthrough technology that changes the way we think about flying vehicles," Sandford said.

Karen Kaplan can be reached at karen.kaplan@latimes.com

# MARS VISION

**M**ars provides several good object lessons in the techniques of observation, and in how what we expect to see often influences what we do see.

About 400 years ago, Danish astronomer Tycho Brahe made the most accurate pre-telescopic observations ever made. Among his targets was the planet Mars. One of his goals was to prove his own theory of the organization of the solar system: he thought all the planets, Earth excepted, went around the Sun in circular orbits, while the Sun went around the Earth.

After he left his island observatory and settled in Prague, he took on an assistant named Johannes Kepler, who undertook to continue the work after Brahe's death. Using the observations in the logs, Kepler determined the laws of planetary motion, which govern every case of one object orbiting another. (Kepler also spent some time inventing a precursory version of the integral calculus, to measure the capacity of the imperial wine barrels, and in defending his mother from charges of sorcery, making him a certified son of a witch.)

Kepler used particularly the observations of Mars in his calculations. Had he used one of the other planets, one important detail of these so-called Kepler's Laws might have been missed, to be found out years or decades later by some other astronomer. The detail is that, in general, planetary orbits are elliptical, not circular. The orbit of Mars is very much more elliptical than that of Venus, Jupiter, or Saturn. In fact, the "inconsistencies" of Mars' motion eventually forced Kepler to

realize that the orbit was elliptical, not circular, blowing apart the ancient notion that planets must travel in circles because they are celestial.

Much later, in the nineteenth century, people began to believe that it might be possible that there were living beings on planets other than Earth, and Mars was thought of as a likely candidate. One of the foremost observers of Mars was Giovanni Schiaparelli, an Italian astronomer working in the late nineteenth and early twentieth centuries. He made many observations and sketches of Mars, and wrote that he saw "canali" on its surface. That word should be translated as "channels" but the similarity to the English word "canal" was too hard to resist. And, whereas channels can be natural or artificial, canals are made.

What fooled Schiaparelli was the natural tendency of the brain, working with the eyes, to make some sense or pattern out of what is seen. The scattering of craters, mountains, and plains we now know exist on Mars from close-up photographs, were at the limits of visibility and resolution for Schiaparelli's telescope. His visual system made lines and patterns where none existed in reality. And other people who saw Schiaparelli's drawings were predisposed to see signs of life, so they saw what they expected to see.

Jumping forward to the 1970s, we designed spacecraft to study Mars closely, from orbit and on its surface. So, naturally, we designed instruments to observe what we thought likely, while at the same time meeting the constraints of weight, size, and data gathering and transmission dictated

by the spacecraft. Among the instruments were several designed to see if life existed or had existed there, including a camera.

I think it was Carl Sagan who remarked that the cameras aboard the *Viking* landers were actually incapable, under certain conditions, of detecting if elephants lived on Mars. The camera worked by taking a vertical scan of its field of view, then rotating the camera head slightly and making another scan. All this was done fairly slowly. So, if an elephant had walked by very close to the camera, it would have registered as either a huge gray wall if it was walking in the direction the camera head rotated, or as a thin gray vertical line if it walked in the opposite direction. In either case, we would not have detected the elephant. (In case you slept through the 1970s, no elephants or other life were found there.)

There are many other cases in the history of science where the major discoveries were made because we realized that there was a new way to see something we had been looking at all the time. It's rather like the situation where Dr. John Watson, having examined some evidence, told Sherlock Holmes, "I see," and the sleuth retorted, "You see, but you do not perceive."

Of course it is natural to design our experiments to observe what we are expecting or familiar with. But we need to keep in mind that new ways of seeing may bring the insight we have been looking for.

A preconceived notion often mars progress. ☆

*Dr. Mark Chartrand is a consultant and freelance writer in Baltimore, MD.*





# The Case For Colonizing Mars

**By Robert Zubrin**

## Mars Is The New World

Among extraterrestrial bodies in our solar system, Mars is singular in that it possesses all the raw materials required to support not only life, but a new branch of human civilization. This uniqueness is illustrated most clearly if we contrast Mars with the Earth's Moon, the most frequently cited alternative location for extraterrestrial human colonization.

In contrast to the Moon, Mars is rich in carbon, nitrogen, hydrogen and oxygen, all in biologically readily accessible forms such as carbon dioxide gas, nitrogen gas, and water ice and permafrost. Carbon, nitrogen, and hydrogen are only present on the Moon in parts per million quantities, much like gold in seawater. Oxygen is abundant on the Moon, but only in tightly bound oxides such as silicon dioxide ( $\text{SiO}_2$ ), ferrous oxide ( $\text{Fe}_2\text{O}_3$ ), magnesium oxide ( $\text{MgO}$ ), and aluminum oxide ( $\text{Al}_2\text{O}_3$ ), which require very high energy processes to reduce. Current knowledge indicates that if Mars were smooth and all its ice and permafrost melted into liquid water, the entire planet would be covered with an ocean over 100 meters deep. This contrasts strongly with the Moon, which is so dry that if concrete were found there, Lunar colonists would mine it to get the water out. Thus, if plants could be grown in greenhouses on the Moon (an unlikely proposition, as we've seen) most of their biomass material would have to be imported.

The Moon is also deficient in about half the metals of interest to industrial society (copper, for example), as well as many other elements of interest such as sulfur and phosphorus.

"This proposition being made publike and coming to the scanning of all, it raised many variable opinions amongst men, and caused many fears & doubts amongst themselves. Some, from their reasons & hops conceived, laboured to stirr up & incourage the rest to undertake and prosecute the same; others, againe, out of their fears, objected against it, & sought to divert from it, aledging many things, and those neither unreasonable nor unprobable; as that it was a great designe, and subjecte to many unconceivable perills & dangers . . .

"It was answered that all great & honourable actions are accompanied with great difficulties, and must be both enterprised and overcome with answerable courages."

—Gov. William Bradford,  
*Of Plimoth Plantation, 1621*

Mars has every required element in abundance. Moreover, on Mars, as on Earth, hydrologic and volcanic processes have occurred that are likely to have consolidated various elements into local concentrations of high-grade mineral ore. Indeed, the geologic history of Mars has been compared to that of Africa, with very optimistic inferences as to its mineral wealth implied as a corollary. In contrast, the Moon has had virtually no history of water or volcanic action, with the result that it is basically composed of trash rocks with very little differentiation into ores that represent useful concentrations of anything interesting.

You can generate power on either the Moon or Mars with solar panels, and here the advantages of the Moon's clearer skies and closer proximity to the Sun than Mars roughly balances the disadvantage of large energy storage requirements created by the Moon's 28-day light-dark cycle. But if you wish to manufacture solar panels, so as to create a self-expanding power base, Mars holds an enormous advantage, as only Mars possesses the large supplies of carbon and hydrogen needed to produce the pure silicon required for producing photovoltaic panels and other electronics. In addition, Mars has the potential for wind-generated power while the Moon clearly does not. But both solar and wind offer relatively modest power potential—tens or at most hundreds of kilowatts here or there. To create a vibrant civilization you need a richer power base, and this Mars has both in the short and medium term in the form of its geothermal power resources, which offer potential for large numbers of locally created electricity generating stations in the 10 MW (10,000 kilowatt) class. In

the long-term, Mars will enjoy a power-rich economy based upon exploitation of its large domestic resources of deuterium fuel for fusion reactors. Deuterium is five times more common on Mars than it is on Earth, and tens of thousands of times more common on Mars than on the Moon.

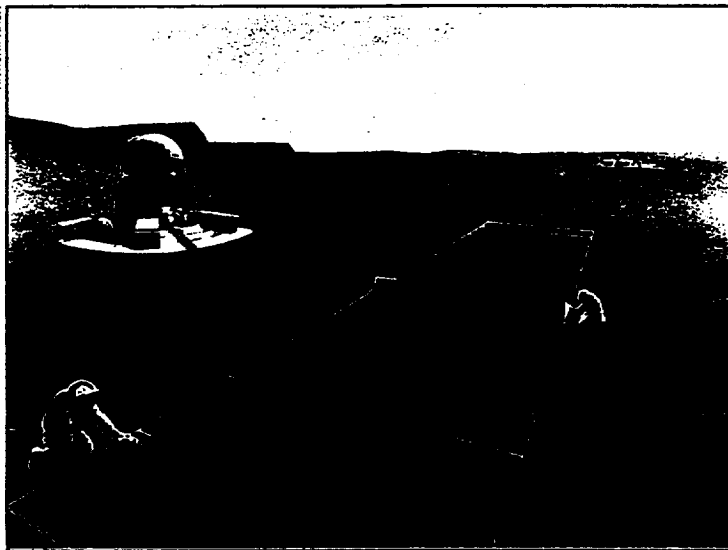
But the biggest problem with the Moon, as with all other airless planetary bodies and proposed artificial free-space

be rapidly manufactured and deployed, opening up large areas of the surface to both shirtsleeve human habitation and agriculture. That's just the beginning, because it will eventually be possible for humans to substantially thicken Mars' atmosphere by forcing the regolith to outgas its contents through a deliberate program of artificially induced global warming. Once that has been accom-

plished, the habitation domes could be virtually any size, as they would not have to sustain a pressure differential between their interior and exterior. In fact, once that has been done, it will be possible to raise specially bred crops outside the domes.

The point to be made is that unlike colonists on any known extraterrestrial body, Martian colonists will be able to live on the surface, not in tunnels, and move about freely and grow crops in the light of day. Mars is a place where humans can live and multiply to large numbers, supporting themselves with products of every description made out of indigenous materials. Mars is thus a place where an actual civilization, not just a mining or scientific outpost, can be developed. And significantly for interplanetary commerce, Mars and Earth are the only two locations in the solar system where humans will be able to grow crops for export.

Artwork: NASA



Astronauts lay out a photovoltaic power array on the surface of Mars.

colonies, is that sunlight is not available in a form useful for growing crops. A single acre of plants on Earth requires four megawatts of sunlight power, a square kilometer needs 1,000 MW. The entire world put together does not produce enough electrical power to illuminate the farms of the state of Rhode Island, that agricultural giant. Growing crops with electrically generated light is just economically hopeless. But you can't use natural sunlight on the Moon or any other airless body in space unless you put walls on the greenhouse thick enough to shield out solar flares, a requirement that enormously increases the expense of creating cropland. Even if you did that, it wouldn't do you any good on the Moon, because plants won't grow in a light/dark cycle lasting 28 days.

But on Mars there is an atmosphere thick enough to protect crops grown on the surface from solar flare. Therefore, thin-walled inflatable plastic greenhouses protected by unpressurized UV-resistant hard-plastic shield domes can be used to rapidly create cropland on the surface. Even without the problems of solar flares and month-long diurnal cycle, such simple greenhouses would be impractical on the Moon as they would create unbearably high temperatures. On Mars, in contrast, the strong greenhouse effect created by such domes would be precisely what is necessary to produce a temperate climate inside. Such domes up to 50 meters in diameter are light enough to be transported from Earth initially, and later on they can be manufactured on Mars out of indigenous materials. Because all the resources to make plastics exist on Mars, networks of such 50- to 100-meter domes could

## Interplanetary Commerce

Mars is the best target for colonization in the solar system because it has by far the greatest potential for self-sufficiency. Nevertheless, even with optimistic extrapolation of robotic manufacturing techniques, Mars will not have the division of labor required to make it fully self-sufficient until its population numbers in the millions. Thus, for decades and perhaps longer, it will be necessary, and forever desirable, for Mars to be able to import specialized manufactured goods from Earth. These goods can be fairly limited in mass, as only small portions (by weight) of even very high-tech goods are actually complex. Nevertheless, these smaller sophisticated items will have to be paid for, and the high costs of Earth-launch and interplanetary transport will greatly increase their price. What can Mars possibly export back to Earth in return?

It is this question that has caused many to incorrectly deem Mars colonization intractable, or at least inferior in prospect to the Moon. For example, much has been made of the fact that the Moon has indigenous supplies of helium-3, an isotope not found on Earth and which could be of considerable value as a fuel for second generation thermonuclear fusion reactors. Mars has no known helium-3 resources. On the other hand, because of its complex geologic history, Mars may have concentrated mineral ores, with much greater concentrations of precious metal ores readily available than is currently the case on Earth—because the terrestrial ores have been heavily scavenged by humans for

the past 5,000 years. If concentrated supplies of metals of equal or greater value than silver (such as germanium, hafnium, lanthanum, cerium, rhenium, samarium, gallium, gadolinium, gold, palladium, iridium, rubidium, platinum, rhodium, europium, and a host of others) were available on Mars, they could potentially be transported back to Earth for a substantial profit. Reusable Mars-surface based single-stage-to-orbit vehicles would haul cargoes to Mars orbit for transportation to Earth via either cheap expendable chemical stages manufactured on Mars or reusable cycling solar or magnetic sail-powered interplanetary spacecraft. The existence of such Martian precious metal ores, however, is still hypothetical.

But there is one commercial resource that is known to exist ubiquitously on Mars in large amount—deuterium. Deuterium, the heavy isotope of hydrogen, occurs as 166 out of every million hydrogen atoms on Earth, but comprises 833 out of every million hydrogen atoms on Mars. Deuterium is the key fuel not only for both first and second generation fusion reactors, but it is also an essential material needed by the nuclear power industry today. Even with cheap power, deuterium is very expensive; its current market value on Earth is about \$10,000 per kilogram, roughly fifty times as valuable as silver or 70% as valuable as gold. This is in today's pre-fusion economy. Once fusion reactors go into widespread use deuterium prices will increase. All the in-situ chemical processes required to produce the fuel, oxygen, and plastics necessary to run a Mars settlement require water electrolysis as an intermediate step. As a by-product of these operations, millions, perhaps billions, of dollars worth of deuterium will be produced.

Ideas may be another possible export for Martian colonists. Just as the labor shortage prevalent in colonial and nineteenth century America drove the creation of "Yankee ingenuity's" flood of inventions, so the conditions of extreme labor shortage combined with a technological culture that shuns impractical legislative constraints against innovation will tend to drive Martian ingenuity to produce wave after wave of invention in energy production, automation and robotics, biotechnology, and other areas. These inventions, licensed on Earth, could finance Mars even as they revolutionize and advance terrestrial living standards as forcefully as nineteenth century American invention changed Europe and ultimately the rest of the world as well.

Inventions produced as a matter of necessity by a practical intellectual culture stressed by frontier conditions can make Mars rich, but invention and direct export to Earth are not the only ways that Martians will be able to make a fortune. The other route is via trade to the asteroid belt, the band of small, mineral-rich bodies lying between the orbits of Mars and Jupiter. There are about 5,000 asteroids known today, of which about 98% are in the "Main Belt" lying between Mars and Jupiter, with an average distance from the Sun of about

2.7 astronomical units, or AU. (The Earth is 1.0 AU from the Sun.) Of the remaining two percent known as the near-Earth asteroids, about 90% orbit closer to Mars than to the Earth. Collectively, these asteroids represent an enormous stockpile of mineral wealth in the form of platinum group and other valuable metals.

Miners operating among the asteroids will be unable to produce their necessary supplies locally. There will thus be a need to export food and other necessary goods from either Earth or Mars to the Main Belt. Mars has an overwhelming positional advantage as a location from which to conduct such trade.

## Historical Analogies

The primary analogy I wish to draw is that Mars is to the new age of exploration as North America was to the last. The Earth's Moon, close to the metropolitan planet but impoverished in resources, compares to Greenland. Other destinations, such as the Main Belt asteroids, may be rich in potential future exports to Earth but lack the preconditions for the creation of a fully developed indigenous society; these compare to the West Indies. Only Mars has the full set of resources required to develop a native civilization, and only Mars is a viable target for true colonization. Like America in its relationship to Britain and the West Indies, Mars has a positional advantage that will allow it to participate in a useful way to support extractive activities on behalf of Earth in the asteroid belt and elsewhere.

But despite the shortsighted calculations of eighteenth-century European statesmen and financiers, the true value of America never was as a logistical support base for West Indies sugar and spice trade, inland fur trade, or as a potential market for manufactured goods. The true value of America was as the future home

for a new branch of human civilization, one that as a combined result of its humanistic antecedents and its frontier conditions was able to develop into the most powerful engine for human progress and economic growth the world had ever seen. The wealth of America was in fact that she could support people, and that the right kind of people chose to go to her. People create wealth. People are wealth and power. Every feature of Frontier American life that acted to create a practical can-do culture of innovating people will apply to Mars a hundred-fold.

Mars is a harsher place than any on Earth. But provided one can survive the regimen, it is the toughest schools that are the best. The Martians shall do well. ★

*Dr. Robert Zubrin is Chairman of the Executive Committee of the National Space Society. His book The Case for Mars: The Plan to Settle the Red Planet and the Reason We Must, will be published by the Free Press, a division of Simon & Schuster, in November 1996.*



Mars' complex geology—giant volcano Olympus Mons is one example—could yield concentrated mineral ores for export.

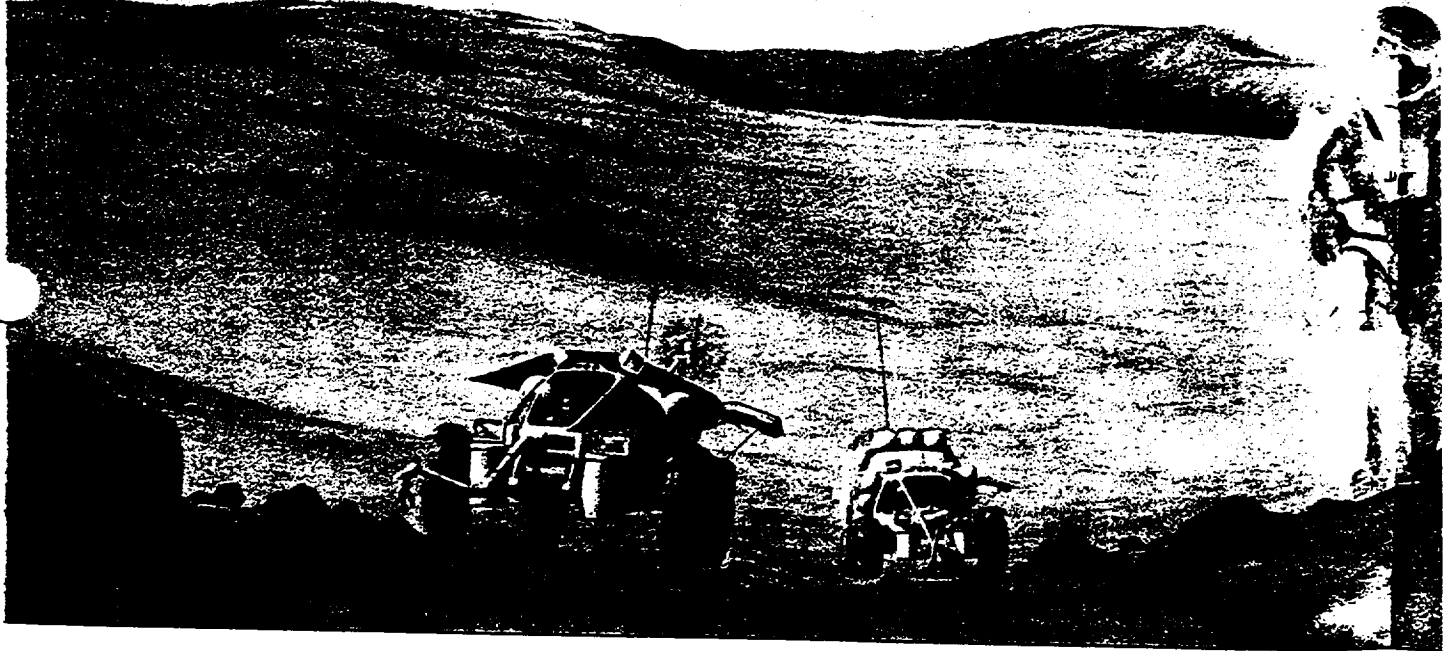
Image: NASA



# THE SIGNIFICANCE OF THE MARTIAN FRONTIER

MARS AS THE FINAL HOPE FOR EARTH

BY ROBERT M. ZUBRIN



A bit more than 100 years ago, a young professor of history from the then-relatively obscure University of Wisconsin got up to speak at the annual conference of the American Historical Association. Frederick Jackson Turner's talk was scheduled as the last one in the evening session. A series of excruciatingly boring papers on topics so obscure that kindness forbids even reprinting their titles preceded Turner's address, yet the majority of the conference participants stayed to hear

him. Perhaps a rumor had gotten afoot that something important was about to be said. If so, it was correct, for in one bold sweep of brilliant insight Turner laid bare the source of the American soul. It was not legal theories, precedents, traditions, national or racial stock that was the source of the egalitarian democracy, individualism and spirit of innovation that characterized America. It was the existence of the frontier.

"To the frontier the American intellect owes its striking characteristics,"

Turner thundered, "That coarseness of strength combined with acuteness and inquisitiveness; that practical, inventive turn of mind, quick to find expedients; that masterful grasp of material things, lacking in the artistic but powerful to effect great ends; that restless, nervous energy; that dominant individualism, working for good and evil, and withal that buoyancy and exuberance that comes from freedom—these are the traits of the frontier, or traits called out elsewhere because of the existence of the frontier."



Turner rolled on, ramming his points home, "For a moment, at the frontier, the bonds of custom are broken and unrestraint is triumphant. There is no tabula rasa. The stubborn American environment is there with its imperious summons to accept its conditions; the inherited ways of doing things are also there; and yet, in spite of the environment, and in spite of custom, each frontier did indeed furnish a new opportunity, a gate of escape from the bondage of the past; and freshness,

and confidence, and scorn of older society, impatience of its restraints and its ideas, and indifference to its lessons, have accompanied the frontier."

"What the Mediterranean Sea was to the Greeks, breaking the bonds of custom, offering new experiences, calling out new institutions and activities, that, and more, the ever retreating frontier has been so to the United States directly, and to the nations of Europe more remotely. And now, four centuries from the discovery of America, at the

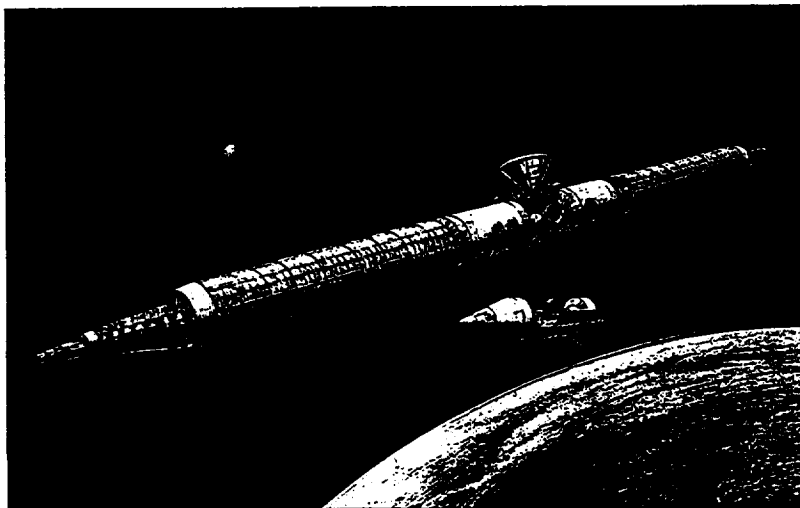
end of a hundred years of life under the Constitution, the frontier has gone..."

The Turner thesis was a bombshell, which within a few years created an entire school of historians who proceeded to demonstrate that not only American culture, but the entire western progressive humanist civilization that America has generally represented in its most distilled form resulted from the great frontier of global settlement opened to Europe by the Age of Exploration.

Turner presented his paper in 1893. Just three years earlier, in 1890, the American frontier was declared closed: the line of settlement that had always defined the furthest existence of western expansion had actually met the line of settlement coming east from California. Now, a century later, we face the question that Turner himself posed—what if the frontier is gone? What happens to America and all it has stood for? Can a free, egalitarian, democratic, innovating society with a can-do spirit be preserved in the absence of room to grow?

the progressive humanistic culture that America has offered to the world for the past several centuries is fading. The issue is not just one of national loss—human progress needs a vanguard, and no replacement is in sight.

The creation of a new frontier thus presents itself as America's and humanity's greatest social need. Nothing is more important: Apply what palliatives you will, without a frontier to grow in, not only American society, but the entire global civilization based upon Western enlightenment values of humanism, reason, science and progress will die.



Artwork: Carole E. Egan

Perhaps the question was premature in Turner's time, but not now. Currently we see around us an ever more apparent loss of vigor of American society: increasing fixity of the power structure and bureaucratization of all levels of society; impotence of political institutions to carry off great projects; the cancerous proliferation of regulations affecting all aspects of public, private and commercial life; the spread of irrationalism; the banalization of popular culture; the loss of willingness by individuals to take risks, to fend for themselves or think for themselves; economic stagnation and decline; the deceleration of the rate of technological innovation and a loss of belief in the idea of progress itself. Everywhere you look, the writing is on the wall.

Without a frontier from which to breathe life, the spirit that gave rise to

I believe that humanity's new frontier can only be on Mars.

### MARS HAS WHAT IT TAKES

Why Mars? Why not on Earth, under the oceans or in such remote region as Antarctica? And if it must be in space, why on Mars? Why not on the Moon or in artificial satellites in orbit about the Earth?

It is true that settlements on or under the sea or in Antarctica are entirely possible, and their establishment and access would be much easier than that of Martian colonies. Nevertheless, the fact of the matter is that at this point in history such terrestrial developments cannot meet an essential requirement for a frontier—to wit, they are insufficiently remote to allow for the free development of a new society. In this day and age, with modern terrestrial com-

munication and transportation systems, no matter how remote or hostile the spot on Earth, the cops are too close. If people are to have the dignity that comes with making their own world, they must be free of the old.

Why then not the Moon? The answer is because there's not enough there. True, the Moon has a copious supply of most metals and oxygen, in the form of oxidized rock, and a fair supply of solar energy, but that's about it. For all intents and purposes, the Moon has no hydrogen, nitrogen or carbon—three of the four elements most necessary for life. (They are present in the Lunar soil, but only in parts per million quantities, somewhat like gold in sea water. If there were concrete on the Moon, Lunar colonists would mine it to get its water out.) You could bring seeds to the Moon and grow plants in enclosed greenhouses there, but nearly every atom of carbon, nitrogen and hydrogen that goes into making those plants would have to be imported from another planet. While sustaining a Lunar scientific base under such conditions is relatively straightforward, growing a civilization there would be impossible. The difficulties involved in supporting significant populations in artificial orbiting space colonies would be even greater.

Mars has what it takes. It's far enough away to free its colonists from intellectual, legal, or cultural domination by the old world, and rich enough in resources to give birth to a new. The Red Planet may appear at first glance to be a desert, but beneath its sands are oceans of water in the form of permafrost, enough in fact (if it were melted and Mars' terrain were smoothed out) to cover the entire planet with an ocean several hundred meters deep. Mars' atmosphere is mostly carbon-dioxide, providing enormous supplies of the two most important biological elements in a chemical form from which they can be directly taken up and incorporated into plant life. Mars has nitrogen too, both as a minority constituent in its atmosphere (three percent) and probably as nitrate beds in its soil as well. For the rest, all the metals, silicon, sulfur, phosphorus, inert gases and other raw materials needed to create not only life but an

advanced technological civilization can readily be found on Mars.

The United States has, today, all the technology needed to send humans to Mars. If a "travel light and live off the land" strategy such as the Mars Direct plan were adopted, then the first human exploration mission could be launched within 10 years at a cost per year less than 20 percent of NASA's existing budget.

Once humans have reached Mars, bases could rapidly be established to support not only exploration, but experimentation to develop the broad range of civil, agricultural, chemical and industrial engineering techniques required to turn the raw materials of Mars into food, propellant, ceramics,

### WHY HUMANITY NEEDS MARS

*"Everything has tended to regenerate them; new laws, a new mode of living, a new social system; here they are become men."*

Jean de Crevecoeur, Letters from an American Farmer, 1782

To see best why 21st century humanity will desperately need an open frontier on Mars, we need to look at modern Western humanist culture and see what makes it so much more desirable a mode of society than anything that has ever existed before. Then we need to see how everything we hold dear will be wiped out if the frontier remains closed.

The essence of humanist society is that it values human beings—human

Firstest," none of these could be displaced. Furthermore, not only had the leading roles been chosen, but so had those of the supporting cast and chorus, and there were only so many such parts to go around. If you wanted to keep your part, you had to keep your place, and there was no place for someone without a part.

The New World changed all that by supplying a place in which there were no established ruling institutions, an improvisational theater big enough to welcome all comers with no parts assigned. On such a stage, the players are not limited to the conventional role of actors—they become playwrights and directors as well. The unleashing of creative talent that such a novel situa-

## IN THIS DAY AND AGE, NO MATTER HOW REMOTE OR HOSTILE THE SPOT ON EARTH, THE COPS ARE TOO CLOSE.

plastics, metals, wires, structures, habitats, etc. As these techniques are mastered, Mars will become capable of supporting an ever-increasing population, with an expanding division of labor, capable of mounting engineering efforts on an exponentially increasing scale.

Once the production infrastructure is in place, populating Mars will not be a problem—under current medical conditions an immigration rate of 100 people per year would produce population growth on Mars in the 21st century comparable to that which occurred in Colonial America in the 17th. Within a century, an engineering capability could be created on Mars with the capability to literally transform the planet, if not to a fully Earth-like environment, at least to the warm, wet conditions of Mars' primitive past, making a desert world into a home for a new spectrum of descendants of terrestrial life.

Mars is remote and can be settled. The fact that Mars can be settled and altered defines it as the New World that can create the basis for a positive future for terrestrial humanity for the next several centuries.

life and human rights are held precious beyond price. Such notions have been for several thousand years the core philosophical values of Western civilization, dating back to the Greeks and the Judeo-Christian ideas of the divine nature of the human spirit. Yet they could never be implemented as a practical basis for the organization of society until the great explorers of the age of discovery threw open a New World in which the dormant seed of humanism contained within medieval Christendom could grow and blossom forth into something the likes of which the world had never seen before.

The problem with Christendom was that it was fixed—it was a play for which the script had been written and the leading roles both chosen and assigned. The problem was not that there were insufficient natural resources to go around—medieval Europe was not heavily populated, and there were plenty of forests and other wild areas—the problem was that all the resources were owned. A ruling class had been selected and a set of ruling institutions, ideas and customs had been selected, and by the law of "Survival of the

tion allows is not only a great deal of fun for those lucky enough to be involved, it changes the view of the spectators as to the capabilities of actors in general. People who had no role in the old society could define their role in the new. People who did not "fit in" in the Old World could discover and demonstrate that far from being worthless, they were invaluable in the new, *whether they went there or not.*

The New World destroyed the basis of aristocracy and created the basis of democracy. It allowed the development of diversity by allowing escape from those institutions that imposed uniformity. It destroyed a closed intellectual world by importing unsanctioned data and experience. It allowed progress by escaping the hold of those institutions whose continued rule required continued stagnation, and it drove progress by defining a situation in which innovation to maximize the capabilities of the limited population available was desperately needed. It raised the dignity of workers by raising the price of labor and by demonstrating for all to see that human beings can be the creators of their world. In America, from



Colonial times through the 19th century when cities were rapidly being built, people understood that America was not something one simply lived in—it was a place one helped build. People were not simply inhabitants of their world. They were makers of their world.

### A TALE OF TWO WORLDS

Consider the probable fate of humanity in the 21st century under two conditions—with a Martian frontier and without it.

In the 21st Century, without a Martian frontier, there is no question that human diversity will decline severely. Already, in the late 20th century, advanced communication and transportation technologies have eroded the

preceding 30 years and the 30 years before that.

Between 1903 and 1933 the world was revolutionized: Cities were electrified; telephones and broadcast radio became common; talking motion pictures appeared; automobiles became practical; and aviation progressed from the Wright Flyer to the DC-3 and Hawker Hurricane. Between 1933 and 1963 the world changed again, with the introduction of color television, communication satellites and interplanetary spacecraft, computers, antibiotics, scuba gear, nuclear power, Atlas, Titan, and Saturn rockets, Boeing 727's and SR-71's. Compared to these changes, the technological innovations from 1963 to the present are insignificant. Immense changes should have oc-

nological breakthroughs that will dramatically advance the human condition in the 21st.

A prime example of the Martian frontier driving new technology will undoubtedly be found in the arena of energy production. As on Earth, an ample supply of energy will be crucial to the success of Mars settlements. The Red Planet does have one major energy resource that we currently know about: deuterium, which can be used as the fuel in nearly waste-free thermonuclear fusion reactors. Earth has large amounts of deuterium too, but with all of the existing investments in other, more polluting forms of energy production, the research that would make possible practical fusion power reactors has been allowed to stagnate.

## MARS TODAY WAITS FOR THE CHILDREN OF THE OLD FRONTIER, BUT MARS WILL NOT WAIT FOREVER.

healthy diversity of human cultures on Earth, and this tendency can only accelerate in the 21st. On the other hand, if the Martian frontier is opened, then this same process of technological advance will also enable us to establish a new branch of human culture on Mars and eventually worlds beyond. The precious diversity of humanity can thus be preserved on a broader field, but only on a broader field. One world will be just too small a domain to allow the preservation of the diversity needed not just to keep life interesting, but to assure the survival of the human race.

Without the opening of a new frontier on Mars, continued Western civilization faces the risk of technological stagnation. To some this may appear to be an outrageous statement, as the present age is frequently cited as one of technological wonders. In fact, however, the rate of progress within our society has been decreasing and at an alarming rate. To see this, it is only necessary to step back and compare the changes that have occurred in the past 30 years with those that occurred in the

curved during this period, but did not. Had we been following the previous 60 years' technological trajectory, we today would have videotelephones, solar powered cars, maglev trains, fusion reactors, hypersonic intercontinental travel, regular passenger transportation to orbit, undersea cities, open-sea mariculture and human settlements on the Moon and Mars. Instead, today we see important technological developments, such as nuclear power and biotechnology, being blocked or enmeshed in political controversy—we are slowing down.

Now, consider a nascent Martian civilization: Its future will depend critically upon the progress of science and technology. Just as the inventions produced by the "Yankee Ingenuity" of frontier America were a powerful driving force on worldwide human progress in the 19th century, so the "Martian Ingenuity" born in a culture that puts the utmost premium on intelligence, practical education and the determination required to make real contributions will make much more than its fair share of the scientific and tech-

The Martian colonists are certain to be much more determined to get fusion on-line, and in doing so will massively benefit the mother planet as well.

The parallel between the Martian frontier and that of 19th century America as technology drivers is, if anything, vastly understated. America drove technological progress in the last century because its western frontier created a perpetual labor shortage back East, thus forcing the development of labor saving machinery and providing a strong incentive for improvement of public education so that the skills of the limited labor force available could be maximized. This condition no longer holds true in America. In fact, far from prizing each additional citizen, immigrants are no longer welcome here, and a vast "service sector" of bureaucrats and menials has been created to absorb the energies of the majority of the population which is excluded from the productive parts of the economy. Thus in the late 20th century, and increasingly in the 21st, each additional citizen is and will be regarded as a burden.

On 21st century Mars, on the other hand, conditions of labor shortage will apply with a vengeance. Indeed, it can be safely said that no commodity on 21st century Mars will be more precious, more highly valued and more dearly paid for than human labor time. Workers on Mars will be paid more and treated better than their counterparts on Earth. Just as the example of 19th century America changed the way the common man was regarded and treated in Europe, so the impact of progressive Martian social conditions will be felt on Earth as well as on Mars. A new standard will be set for a higher form of humanist civilization on Mars, and, viewing it from afar, the citizens of Earth will rightly demand nothing less for themselves.

The frontier drove the development of democracy in America by creating a self-reliant population which insisted on the right to self-government. It is doubtful that democracy can persist without such people. True, the trappings of democracy exist in abundance in America today, but meaningful public participation in the process has all but disappeared. Consider that no representative of a new political party has been elected president of the United States since 1860. Likewise, neighborhood political clubs and ward structures that once allowed citizen participation in party deliberations have vanished. And with a re-election rate of 95 percent, the U.S. Congress is hardly susceptible to the people's will. Regardless of the will of Congress, the real laws, covering ever broader areas of economic and social life, are increasingly being made by a plethora of regulatory agencies whose officials do not even pretend to have been elected by anyone.

Democracy in America and elsewhere in western civilization needs a shot in the arm. That boost can only come from the example of a frontier people whose civilization incorporates the ethos that breathed the spirit into democracy in America in the first place. As Americans showed Europe in the last century, so in the next the Martians can show us the path away from oligarchy.

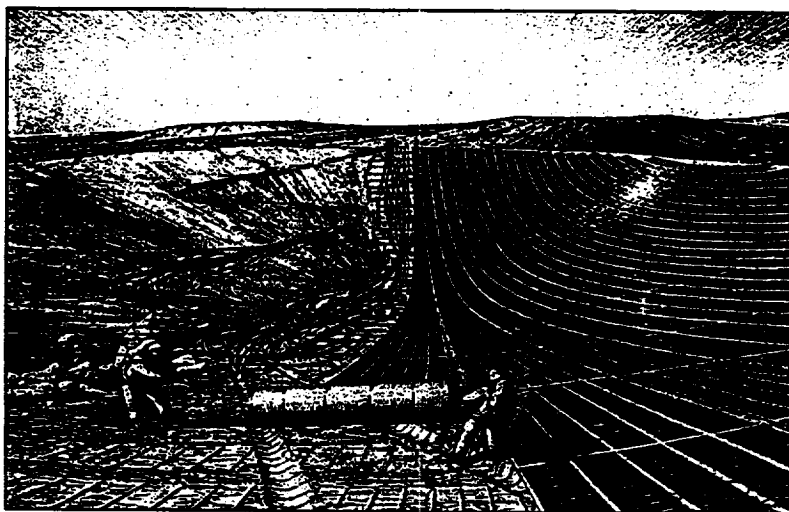
There are greater threats that a humanist society faces in a closed world

than the return of oligarchy, and if the frontier remains closed, we are certain to face them in the 21st century. These threats are the spread of various sorts of anti-human ideologies and the development of political institutions that incorporate the notions that spring from them as a basis of operation. At the top of the list of such pathological ideas that tend to spread naturally in a closed society is the Malthus theory, which holds that since the world's resources are more or less fixed, population growth must be restricted or all of us will descend into bottomless misery.

If the world's resources are fixed, then each person is ultimately the enemy of every other person, and each race or nation is the enemy of every other race or nation. The inevitable result is tyranny, war and genocide. Only in a universe of unlimited resources can all men be brothers.

## MARS BECKONS

Western humanist civilization as we know and value it today was born in expansion, grew in expansion and can only exist in a dynamic expanding state. While some form of human society



Artwork: Carter Eismann

Malthusianism is scientifically bankrupt—all predictions made upon it have been wrong, because human beings are not mere consumers of resources. Rather, we create resources by the development of new technologies that find use for them. The more people, the faster the rate of innovation. This is why (contrary to Malthus) as the world's population has increased, the standard of living has increased, and at an accelerating rate. Nevertheless, in a closed society Malthusianism has the appearance of self-evident truth, and herein lies the danger. It is not enough to argue against Malthusianism in the abstract—such debates are not settled in academic journals. Unless people can see broad vistas of unused resources in front of them, the belief in limited resources tends to follow as a matter of course. And if the idea is accepted that

might persist in a non-expanding world, that society will not feature freedom, creativity, individuality, or progress, and placing no value on those aspects of humanity that differentiate us from animals, it will place no value on human rights or human life as well. Such a dismal future might seem an outrageous prediction, except for the fact that for nearly all of its history most of humanity has been forced to endure such static modes of social organization, and the experience has not been a happy one. Free societies are the exception in human history—they have only existed during the four centuries of frontier expansion of the West. That history is now over. The frontier opened by the voyage of Christopher Columbus is now closed. If the era of western humanist society is not to be seen by future historians as some kind of transitory golden age, a

brief shining moment in an otherwise endless chronicle of human misery, then a new frontier must be opened. Mars beckons.

But Mars is only one planet, and with humanity's powers over nature rising exponentially as they would in an age of progress that an open Martian frontier portends, the job of transforming and settling it is unlikely to occupy our energies for more than three or four centuries. Does the settling of Mars then simply represent an opportunity to prolong, but not save a civilization based upon dynamism? Isn't it the case that humanist civilization is ultimately doomed anyway? I think not.

The universe is vast. Its resources, if we can access them, are truly infinite. During the four centuries of the open frontier on Earth, science and technology have advanced at an astonishing pace. The technological capabilities achieved during the 20th century would dwarf the expectations of any observer from the 19th, exceed

**IN THE 21ST  
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SEVERELY.**

the dreams of one from the 18th, and appear outright magical to someone from the 17th century. The nearest stars are incredibly distant, about 100,000 times as far away as Mars. Yet, Mars itself is about 100,000 times as far from Earth as America is from Europe. If the past four centuries of progress have multiplied our reach by so great a ratio, might not four more centuries of freedom do the same again? There is ample reason to believe that they would.

Terraforming Mars will drive the development of new and more powerful sources of energy; settling the Red Planet will drive the development of ever faster modes of space transportation. Both of these capabilities in turn will open up new frontiers ever deeper into the outer solar system, and the harder challenges posed by these new environments will drive the two key technologies of power and propulsion ever more forcefully. The key is not to let the process stop. If it is allowed to stop for any length of time, society will

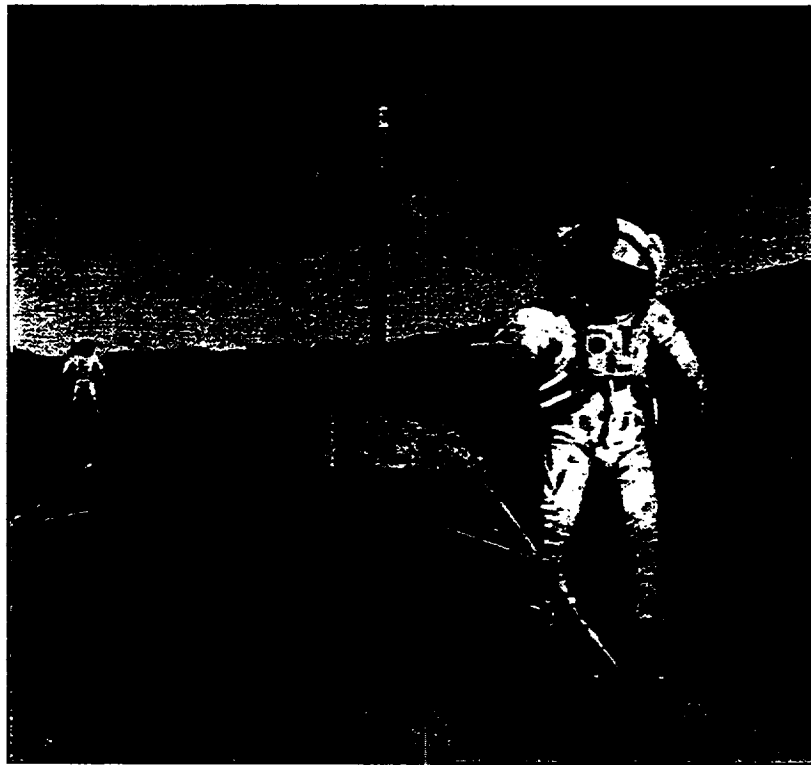


Artwork: Carter Eismann

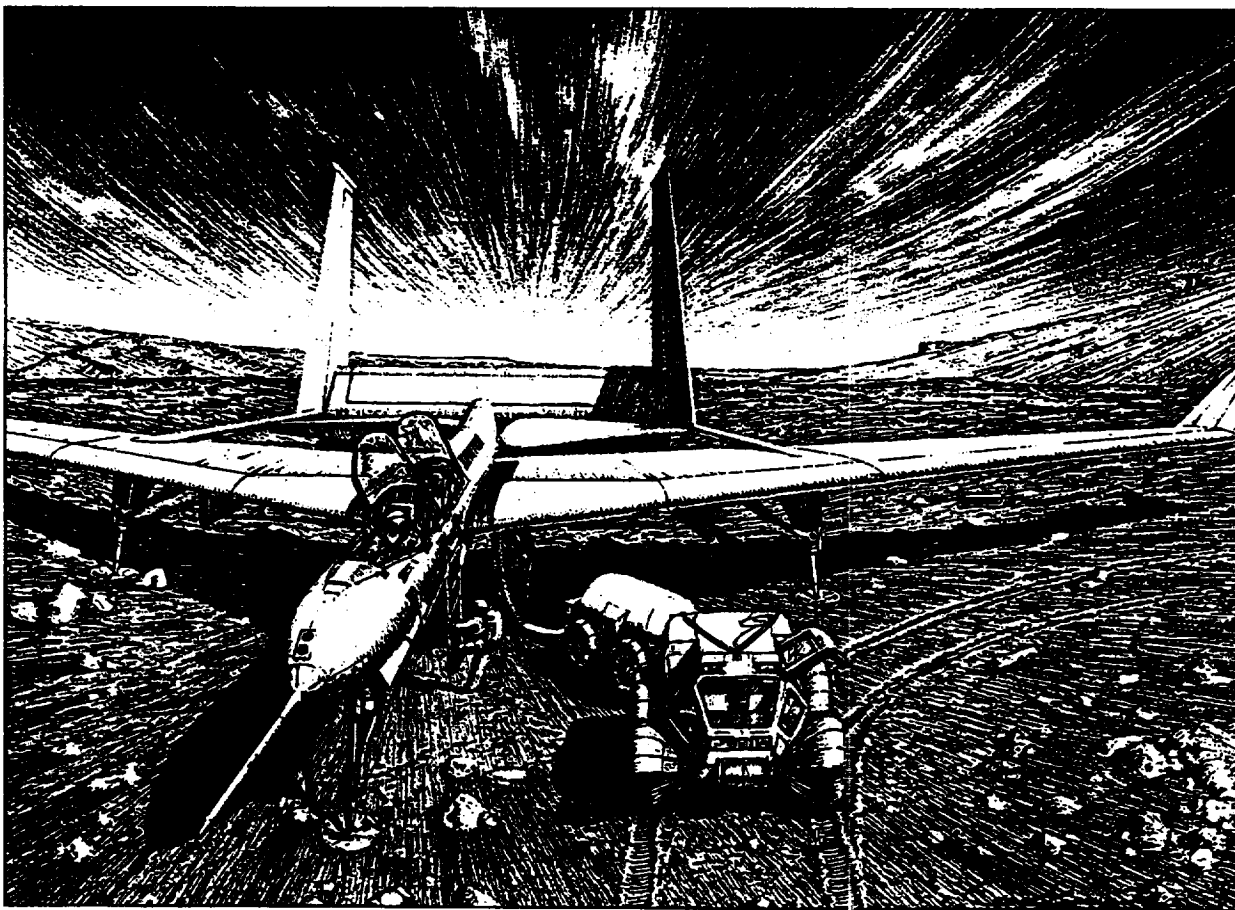
crystallize into a static form that is inimical to the resumption of progress. That is what defines the present age as one of crisis. Our old frontier is closed. The first signs of social crystallization are clearly visible. Yet progress, while slowing, is still extant: Our people still believe in it and our ruling institutions are not yet incompatible with it.

We still possess the greatest gift of the inheritance of a 400-year long Renaissance: To wit, the capacity to initiate another by opening the Martian frontier. If we fail to do so, our culture will not have that capacity long. Mars is harsh. Its settlers will need not only technology, but the scientific outlook, creativity and free-thinking individualistic inventiveness that stand behind it. Mars will not allow itself to be settled by people from a static society—those people won't have what it takes. We still do. Mars today waits for the children of the old frontier, but Mars will not wait forever. ☆

*Dr. Robert Zubrin is a member of the NSS Board of Directors.*



Artwork: Carter Emmart



Artwork: Carter Emmart

# The Once and Future Planet

By Patricia Barnes-Svarney

Earth has then hoped for Mars. It's

not just the delicate clouds that occasionally

wait through the thin Martian atmosphere, nor

the sinuous, river-like valleys that meander

across the surface of the Red Planet that are

our ancient dream of a second Mars. It's

the hope that Mars is a planet that

can be a place where we can live.

It's the hope that Mars is a planet

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It's the hope that Mars is a planet

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straight, dark lines on the planet's surface, giving rise to images of carefully constructed canals and humanoid life. Next came glimpses of Phobos and Deimos, Mars' two minuscule moons. But it was still Mars that held a fascination as the home of an alien race.

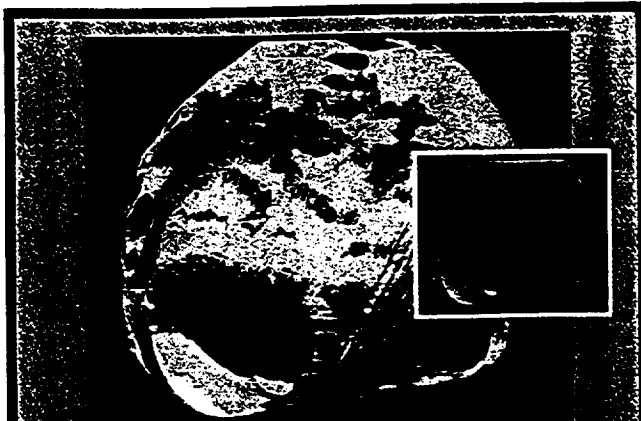
Astronomers such as America's Percival Lowell proposed that the planet held the most civilized of civilizations—a perfect race of perfect creatures on a dying world. We became enamored with the Red Planet, writing stories and tales of great Martian cities that resembled our own. In 1965, *Mariner 4* returned the first closeup photos of a stark and cratered Mars. But, it was not until 1976, when two *Viking* spacecraft soft-landed on Mars that the Martians all but disappeared.

The Red Planet certainly doesn't seem to be home to conditions necessary to support life on the Earth. Measuring just a bit more than half the diameter of Earth in size, with a correspondingly weak gravitational field, the planet holds only a thin blanket of atmosphere 1/10 as dense as Earth's. It is composed of 95 percent carbon dioxide, 2.7 percent nitrogen, 1.6 percent argon, 0.13 percent oxygen and trace amounts of water vapor. Such a thin atmosphere allows lethal amounts of ultraviolet radiation from the Sun to bombard the planet, making life without a spacesuit or life support system unthinkable.

Even though surface temperatures in the equatorial regions of Mars may sometimes climb to 17°C, the planet is, in general, an icebox. Temperatures during the day near the Martian equator may hover around 10°C, but, once the night comes on, they plummet to around -100°C. Overall, a Martian day is a bit warmer than a day on the Jovian moon of Callisto and much colder than the coldest day on Venus.

Major wind storms, usually occurring during the change of seasons, can obscure the view of the planet. These storms sometimes cover the planet like a huge, red rendition of the great Dust Bowl storms of the 1930's that blanketed parts of the United States. Winds can race over the surface at speeds exceeding 320 kilometers per hour, but because the atmospheric pressure on the surface is only about 8 millibars (1/125th Earth's surface pressure or about what you would find at an altitude of 30,000 meters), the winds seem only a tenth as strong-breezes as opposed to gales. Still, the winds are strong enough to sculpt "dust devils," kilometer-high columns of dust that form much like the smaller mini-dust tornadoes along the Earth's deserts.

A suite of spacecraft happened to visit Mars during one of the largest dust storms on record. The storm lasted from November 1971 to February 1972, dates which happened to coincide with the arrival of the former Soviet Union's *Mars 1* and *Mars 2* spacecraft and the United States' *Mariner 9*. Landers from the Soviet craft descended into the maw of the storm only to be lost. *Mariner 9* leisurely orbited the Red Planet, waiting for the skies to clear, and



There is more than one way to make a good moon shot. Spectrometers in portable instruments can be used to measure the spectral lines of the moon's surface. The moon's surface is covered with a variety of minerals, and each has a unique spectral signature. By measuring the intensity of these lines, scientists can determine the composition of the moon's surface. This method is used by the Apollo 16 and 17 lunar surface experiments.

Not too far away is a much smaller, rather isolated, Dalmatian town. The 12 km distance, on average, from the sea is not a disadvantage, as there are beaches and many restaurants. They are often accompanied by streams. No rivers are there, but the water in the river and many, even in the partially filled with organic matter, a lot of fish and fish.

These moons were found in 1877 by Asaph Hall of the United States Naval Observatory in Washington, D.C. during one of his studies of Pallas's closest approaches to Earth if they were indeed what my planet was of the Roman god of war. The moons seem to be out of place and probably belong to the not all that far away asteroid belt. Both seem to be too small to have originated from planetary accretion when there was less

For the visitor to Mars, the view of Phobos and Deimos would be far more frequent than Earth's Luna. Phobos orbits Mars in a leading orbit—seven hours and 40 minutes—rising in the west and setting in the east, traversing the entire sky in only five and one-half hours. Deimos orbits once every 30 hours—from the usual east to west—and would be just a star-like spot in the Martian sky.

But, even if the moons appear to only be rocks in space, there may be reasons for Martian colonists to visit Phobos or Deimos. The spectra of both resemble dark asteroids known as "C-types"—similar to stony meteorites, called carbonaceous chondrites, found on Earth. These asteroids are common to the outer regions of the asteroid belt, lying just inside the orbit of Jupiter. It is probable, though unproven, that the orbital tugging and pulling of Jupiter cast Phobos and Deimos toward the Sun during Mars' final stages of formation and were captured by the new planet's gravity.

What would be found on the two moons? Carbonaceous chondrite meteorites—believed to have originated in the asteroid belt—indicate that the moons may be differentiated like the inner planets, consisting of layers of different material. Both moons may also harbor ultra-primitive organic compounds and ices on their surfaces—ices that could be mined for water, both for the dry Red Planet below and for fuel.

The moons may also be mined for metals and minerals, but with escape velocities of only 14.9 meters per second on Phobos, and 10 meters per second for Deimos—a good fastball would go orbital—the hardest trick might be to find a way to latch yourself to the surface of the moon in the first place. —PBS ☆

then returned a trove of data on the planet.

## HOME FOR US?

Even with the less-than-hospitable weather conditions, Mars and Earth are not so different as one might think. A Martian day (a "sol") is just a half hour longer than an Earth day. There are seasons on Mars thanks to the 25.19° tilt of the planet's axis (Earth's is 23.45°). However, because of Mars' distant orbit around the Sun, the seasonal differences are more extreme than here on Earth. Ice caps at the north and south poles track the changes of the season as they advance and recede. And, perhaps most intriguing, water appears to exist in various forms. Sparse amounts of water ice are found during the summer at the northern polar cap (the winter polar caps are composed of mostly frozen carbon dioxide—dry ice). Occasional morning fog and isolated clouds indicate the presence of water vapor in the atmosphere.

The views of the daytime Martian skies are like Earth, with a few wispy clouds, haze and reflected sunlight. But thicker terrestrial clouds have more moisture to work with, and our bright blue sky would contrast sharply with the Red Planet's pinkish-grey sky, brought about by rust-colored particles spread by the

winds.

The first human explorers to Mars will find a world of physical features in some places reminiscent of, but dwarfing those, of Earth. Boulder fields, chaotic terrain and large and small craters reign in the southern hemisphere of the planet. Toward the north are smooth plains. Impact craters pock the planet, some as deep as those on the Moon, while others have been smoothed by countless centuries of drifting dust.

Large canyons cut across the planet. The greatest of these canyons, Valles Marineris, stretches 4,500 kilometers across the face of the planet—about the distance from Los Angeles to Boston. It plunges to a depth of nearly 5 km in some spots and yawns nearly 250 km wide in others. Many inactive volcanoes stand two or three times higher than the largest on Earth. Olympus Mons, the largest volcano in the solar system, towers some 30,000 meters above the Martian plains. Its caldera, the collapsed opening to the once-molten lava below, has often been mentioned as a landing site, as it may still have active vents that could hold water, heat and, perhaps, life.

Huge dry river beds, reminiscent of the Channeled Scablands of North America's Pacific northwest, scar the Martian surface. The river-like patterns carved in the Martian rock indi-

cate the past presence of a liquid—probably water—that once flowed during a much warmer time in the planet's early history. In order to

support such flows, the atmosphere had to be thicker and warmer. But that potentially nurturing blanket vanished; whether dissipated into space or absorbed by the rock below is unknown.



MARS

## MARS-BOUND

So why go to such a different yet similar planet? There is the need to confirm our theories on the features and origin of the Red Planet. But without question, there are certain physical attributes that give the Red Planet the edge in colonization.

For one thing, there is its gravitational field which, though only 38 percent of the Earth's, would protect explorers from the health hazards of zero-g. The soils are rich with oxides of silica, iron, sulfur, magnesium, aluminum, calcium and titanium, and may be used for growing plants in greenhouses. Soils also could be mined for building materials such as cement or glass. Water could be extracted from the atmosphere for life support needs. Further processing could extract oxygen for life support and fuel needs, and hydrogen which, when combined with the abundant carbon dioxide, would provide methane fuel for both Earth-bound rockets and high-powered jet sleds that might one day propel humans from Martian home to work.

Besides being the best planet to occupy short of Earth, future astro-explorers will find the Red Planet rich in mysteries. Will they find the evidence for life that the *Viking* craft could not detect? Will they find, hidden in the layers of a canyon wall, fossils from a long-gone era when water coursed over the planet?

No matter what is found, Mars may be the future of the human race. A Mars settlement could become a base for the exploration and mining of the asteroid belt and a gateway to the outer planets. Maybe Percival Lowell was right after all. Mars will eventually be occupied by civilized Martians—who look remarkably like us. ☆

*Patricia Barnes-Svarney is a freelance science writer in New York.*



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**Mars 2**  
(USSR, 1971)  
Objective/Findings: Orbiter/lander mission. Orbiter returned data; lander crashed.

The probe was launched in 1970 and was the first to orbit Mars. It was named after the Roman god of war.

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**Viking 2**  
(US, 1975-80)  
Objective/Findings: Successful twin of Viking 1. Lander returned data from both landers and orbiters. Findings were ambiguous from both.

The probe was launched in 1970 and was the first to orbit Mars. It was named after the Roman god of war.

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The probe was launched in 1970 and was the first to orbit Mars. It was named after the Roman god of war.

**Human to Mars**  
(US, 2019)  
Objective/Findings: Proposed human mission to explore resources and study geology as well as search for fossil evidence of life.

Robert Bunge

Exploration never really ends. But there does come a time when you do want to see the forest, not just the trees; a time when the bushwacking comes to an end and you simply want to settle in and take the measure of a place; a time to think globally while scouting locally. Such is the time for Mars, and Mars Observer, the first U.S. spacecraft to the Red Planet in nearly two decades, is the scout.

Researchers from around the world are starting to gear up for a new look at Mars, courtesy of Mars Observer. They are preparing for a cascade of data that will soak up a dozen CD-ROM disks per week. Designed for the long haul, the Observer will spend an entire Martian year showing us what human eyes have never seen before. It will allow us to literally survey Mars.

### KNOWING MARS

Our understanding of Mars has come about in increments, new knowledge being delivered by new technology at each step. As first viewed through a telescope, Mars appeared as a featureless world of reddish-orange hue and little detail. But, with time, astronomers started to record faint details. There was a polar cap. Dark markings on the planet's face were seen and named—Syrtris Major, Sinus Sabaeus and Solis Lacus. Just a few features, but nonetheless, they *are* the only surface features of another planet that can be seen from Earth. Then came tantalizing hints of clouds, dust storms, fogs and frosts.

The next step in knowing Mars came as the *Mariner* and *Viking* space probes beamed back photos of craters, huge volcanoes and massive

valleys. The detail of Mars finally started to come out. A past history of running water and perhaps even life was revealed.

In the realms of complexity and sophistication, perhaps only the Hubble

States returned to Mars.

However, the Red Planet had certainly not been forgotten. For scientists like Arden Albee, *Mars Observer* project scientist, the *Vikings* raised far more questions than they answered. For years, researchers from around the world have been examining their data. One result of all those years of study is the *Mars Observer*.

"Many of the people working on *Mars Observer* have either been using *Viking* data for years or interned on the project," Albee says. "*Viking* was the first time we really explored Mars. It taught us what questions to ask," he adds. "We came up with theories about how Mars works. The *Mars Observer* spacecraft will let us test some of them."

### POLAR CIRCLES ARE BETTER

*Mars Observer* is slated for launch this fall atop a Titan 3 rocket. Soon after achieving Earth orbit, a transfer orbit stage will supply the thrust

needed to escape

Earth's gravity well. During the 11-month cruise toward Mars, on-board thrusters will slow the spacecraft to a point that, as it passes Mars, the Red Planet's gravity will reach out and snare it. Once *Mars Observer* arrives on orbit, a 3.6 by 6.7-meter solar panel will power eight instruments during a 687 Earth-day-long mission that will collect more data than all other planetary missions combined, bar the *Magellan* probe to Venus.

If you compare *Mars Observer* to *Viking*, the first and foremost difference between them is the orbit.



Space Telescope can compare with the spacecraft of the *Viking* project. Two orbiters took tens of thousands of images and recorded mountains of data. Two landers tested the Martian soil for signs of life, returned images of the surface and tracked weather conditions for as long as six years.

And then the new views stopped. For almost a decade, the flow of data almost entirely ceased. And it would be almost 20 years before the United



While the *Viking* orbiters circled near the equator of the Red

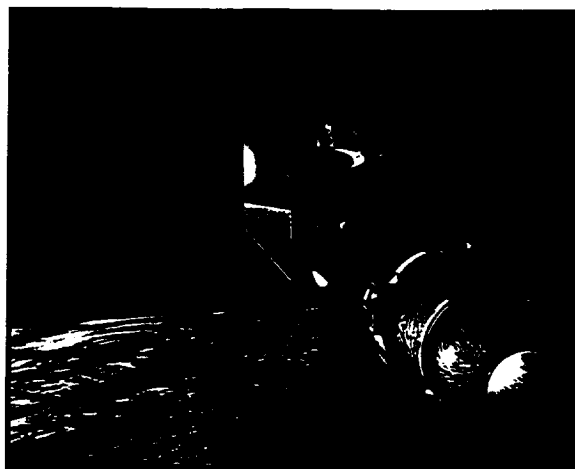
Planet, *Mars Observer* will loop around the poles in an orbit not too dissimilar from many Earth-orbiting science and weather satellites. The spacecraft's initial highly elliptical orbit will be modified over the course of three months by on-board thrusters until the *Observer* cruises in a nearly circular polar orbit. In its final mapping orbit, the spacecraft will be synchronized with the Sun, meaning that from the probe's point of view, the surface will always be illuminated by an early afternoon Sun.

From 380 kilometers above the Martian surface, *Mars Observer* will circle Mars every 118 minutes, traveling southward on the sunlit side and northward on the night side. A unique aspect of *Mars Observer* is that, unlike many other planetary probes, most of the instruments are fixed—there is no moving scan platform. In its final configuration, most of the instruments will be pointed straight toward the Red Planet. Observing a particular spot on Mars will require waiting for the planet to rotate until the area of interest is directly below the spacecraft.

### PACKAGED TO GO

While the spacecraft is operated by the Jet Propulsion Laboratory (JPL) in Pasadena, California, it takes advantage of modern communications to allow scientists to stay in touch with the spacecraft without having to disrupt their lives and move to California for the duration of the two-year mission.

Each Primary Investigator ("PI," there is one for each instrument) has a dedicated data line on a computer network. As data from the spacecraft arrive at Earth, a computer at JPL will automatically route them to the proper researcher. Once received, the scientist will decode the data



Orbital Sciences Corp.'s Transfer Orbit Stage will provide *Mars Observer* with the additional boost it will need to reach Mars in the course of an 11-month journey.

and start the process of analysis. As the data are studied, the PIs will be able to send commands to their instrument via the computer network for forwarding to the spacecraft.

"The PIs have control over their instrument. *Mars Observer* is designed so that the instruments don't interfere with each other," Albee says. "A PI can change sampling rates, data rates and other controls from their home institution without bothering the other instruments. You can't do that if you have lots of instruments on the same scan platform," explains Albee.

In addition, except for the *Mars Observer* Camera (MOC), all of the instruments are designed and ex-

pected to operate around the clock for a full Martian year. Since each instrument has its own microprocessor, data are collected in blocks and saved on a tape recorder until it's time for the daily playback to Earth.

### MARTIAN SNAPSHOTS

Because the MOC is the most data hungry instrument onboard, it isn't possible for it to capture images, 24 hours a day. If it did so, the spacecraft tape recorders would fill up and not have any room for data from other instruments. Instead, the camera will take pre-planned pictures as part of a program

to image the entire planet during each of the seasons with 300-meter resolution. In addition, it will take wide-angle, low-resolution weather pictures on a daily basis.

Once these images are taken and stored, along with data from other instruments, any leftover space on the tape recorders will be filled up with more pictures. It is also expected that once every three days, realtime access to the spacecraft via the NASA Deep Space Network will allow more MOC images to be taken, including high resolution images that will be capable of seeing objects just three meters across—the highest resolution camera system ever sent to another planet.

"We want to use these small area images to sample different types of terrain and to look for changes during different seasons," Albee says. These areas include sand dunes, boulder fields and the tops of volcanoes.

But, Albee is very quick to point out that imaging a specific area isn't going to be easy. The narrow-angle MOC uses a special type of charge coupled device (CCD) camera that will allow it to take a long, narrow image only 2.7 kilometers wide, but many kilometers long. Since the camera isn't on a scanning platform, to take an image of a particular location will require imaging the desired area when it is directly below the spacecraft during just the



The *Viking* probes set the stage for *Mars Observer* with exquisite images from orbit and the surface. The *Observer* science team hopes to image the *Viking* lander sites from orbit with three-meter resolution.

# THE MARS OBSERVER

The Mars Observer probe, scheduled to be launched by a Titan 3 booster this September, will conduct studies of Martian atmosphere, surface and interior over the course of one Martian year (687 Earth days).

## Magnetometers and Electron Reflectometer

Study the Martian magnetic field.

## High Gain Antenna

Communicates with Earth and conducts radio science experiments.

## Solar Array

Powers probe operations; 3.66 x 6.71 m array.

## Thermal Emission Spectrometer

Determines mineral content of rocks and ices; maps their distribution. Determines composition of clouds.

## Mars Observer Camera

Photographs atmosphere and surface.

## Pressure Modulator Infrared Radiometer

Measures atmospheric temperature, water vapor, dust and pressure.

## Mars Balloon Relay

French-built device receives data from Russian probe on Martian surface (see below).

## Laser Altimeter

Creates a global topographic map.

## Gamma Ray Spectrometer

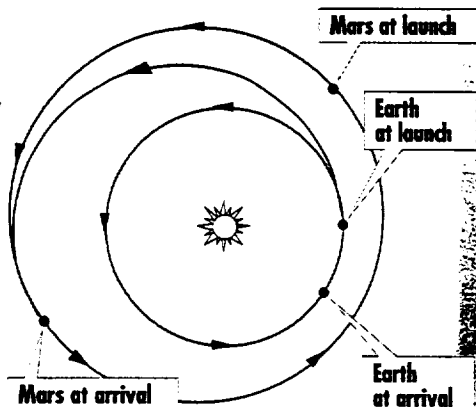
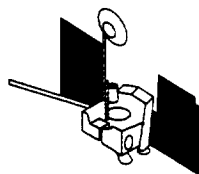
Determines elemental composition of Martian surface.

Figure drawn to scale

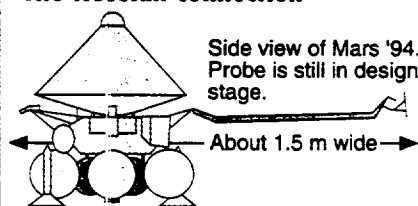
## Getting there

The journey, known as the cruise phase, will take 11 months.

Observer in cruise mode



## The Russian connection



In 1994, Russia will launch Mars '94, a Mars probe that will include two penetrators (devices that plunge into the Martian surface, recording geological information) and two surface-landing scientific packages. The Mars Observer will serve as a data relay for these instruments.

## More about the Observer

- Once it has arrived at Mars, firings of several small onboard thrusters will position the probe in an almost circular polar orbit. Then the mapping phase will begin (approximately December 1993 to October 1995).
- Uses flight-proven components from commercial communication and government weather satellite designs.
- Will be helpful in selecting landing sites for future missions.



right orbit. The length of each strip will depend on how much memory is left in the camera and can fit on the tape recorders. Nonetheless, Albee says the imaging team has tentatively targeted several areas of interest, including the *Viking* lander sites. "We are especially interested in [the lander sites] because we have pictures of what the terrain looks like from the ground. That will help us understand what other areas look like," he notes.

Because of the difficulties of pinpointing high resolution images, Albee can't promise that they will be able to image the lander sites, but he figures they will get better at hitting an exact location toward the end of the mission after they have more experience with the spacecraft.

Nor can Albee promise that they will be able to take high resolution images of the "face"—a curious feature that appears to resemble a human face. "We will try to image the face area whenever possible, but I can't promise high resolution images," he says. But, Albee does say that the human mug of Mars will be imaged—like the rest of the planet—with 300-meter resolution.

### THE MISSING MAGNET

Though most people relate to planetary exploration through the wondrous pictures returned from afar, often times scientists are just as, if not more so, interested in data from other instruments. The Magnetometer and Electron Reflectometer (MAG/ER) will be one such instrument. Notwithstanding that many spacecraft have visited the Red Planet, humans have yet to detect a magnetic field surrounding Mars.

"If Mars has a magnetic field, it's very weak. *Mars Observer* will look for it and measure it. The *Vikings* didn't carry magnetometers, *Mariner* didn't detect a field and the [Russian] *Phobos* missions didn't have a chance to complete their studies," Albee says.

Future explorers and settlers of Mars may also be waiting for the results of other instruments. The Gamma Ray Spectrometer (GRS) is mounted on the end of a six-meter boom that only weighs two kilograms

when on Earth. The GRS will be used to determine the elements and minerals that make up the Martian surface. In addition, GRS might provide some insight to the amount of water near the surface of the planet. The Thermal Emission Spectrometer (TES) will also help pinpoint the makeup and location of Martian ground resources as well as study the chemical makeup of frosts and clouds. TES is similar to an instrument that flew on the *Viking* orbiters, but is much more sensitive, according to Albee.

The Pressure Modulator Infrared Radiometer (PMIRR) will serve as one of *Mars Observer's* weather instruments. It will track atmospheric temperature, the amount of water vapor and dust in the air and collect atmospheric pressure profiles. Like similar instruments on Earth Observing System satellites, PMIRR will also track the movement of carbon dioxide. With all of these instruments, it's important to remember that *Mars Observer's* 93° inclination orbit will finally allow detailed study of the unexplored Martian poles.

### LASER HO!

The Mars Observer Laser Altimeter (MOLA), according to Albee, was originally planned to be a radar altimeter—similar to the one on the *Magellan* Venus probe. It is the first such laser experiment to fly on a planetary probe. MOLA Primary Investigator David E. Smith of Goddard Space Flight Center in Greenbelt, Maryland, said that MOLA took about three years to build and cost about \$10 million. The decision to change from radar to laser was made in 1987 during a round of cost cutting. The radar altimeter would have cost about \$25 million.

While the radar would have recorded the height of an area several kilometers in diameter—referred to as a "footprint"—the laser has a footprint about 120 meters across. The payoff is that the radar would have been accurate to a few meters, but the laser will pinpoint the altitude of the footprint area to about 1.5 meters.

To do this, the laser will shoot out a beam of light, once every 10 nanoseconds. Thus, each pulse of light will be about 1.5-meters long. MOLA will then record the amount of time before the flash is returned to

the spacecraft. Smith says that by the end of the mission, he should have at hand north to south tracks of MOLA observations spaced out about every 1.5 kilometers with spots every 300 meters along those tracks. Because of the polar orbit, the tracks will converge near poles, providing even better coverage in these relatively uncharted regions. These detailed data of the poles are vital to understanding the dynamics and makeup of the polar caps and the weather systems around them. "We are excited about the poles. If the polar caps vary in thickness on the order of 50 or so centimeters during the course of the year, we will be able to measure it," Smith says.

The last science instrument does double duty. The high gain radio antenna that sends data back to Earth will also serve as the radio science instrument. An ultra-stable oscillator will allow team members to monitor the gravitational field of Mars and provide temperature profiles of the Martian atmosphere. In addition, according to Smith, who is also on the radio science team, this experiment will provide daily distance information between Earth and Mars, accurate to three meters, for an entire Martian year. "*Mars Observer* is the first planetary spacecraft capable of quality geodetic science collection," he notes, adding that the orbital data from *Mars Observer* will keep the folks who study planetary motion busy for years.

While several European countries are supplying parts—the Electron Reflectometer came from France—perhaps the most noteworthy international venture is a radio relay instrument that will beam signals from the Russian *Mars 94/96* landers back to Earth. Supplied by France, the relay equipment allows *Mars Observer* to serve as a forward deployed communications satellite.

Even though it's just an orbiter, *Mars Observer* is an exciting mission. Today, the *Viking* data are what we know about Mars. In the years ahead, *Mars Observer* data will show us a new Red Planet and perhaps blaze a trail through the depths of space for humans on their first trip to another planet. ★

Robert Bunge is Associate Editor of *Ad Astra*.



# l s m a r s

At first glance,

the **red planet**

seems barren

and lifeless,

But according

to one scientist,

**appearances**

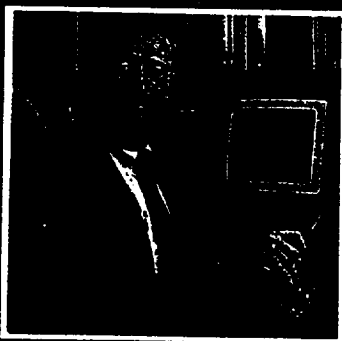
can be

**deceiving.**

by Bob Schoen

# alive?





**Dr. Gilbert Levin (above) designed the Labeled Release Experiment, which flew aboard the Viking landers that arrived at Mars in 1976. The experiment displayed positive indications for microbial life.**

**in** 1976, Viking I and Viking II arrived at Mars and deployed two robotic probes on the planet's surface. Onboard the two landers were three small biology experiments: the Gas Exchange Experiment (GEx), the Pyrolytic Release Experiment (PR) and the Labeled Release Experiment (LR). In the days and weeks that followed, each of these experiments displayed positive indications for microbial life. As the data was coming in and being reviewed, however, controversy began to develop among the project scientists, who were working independently of one another. The GEx and PR experiments failed to repeat their initial results. Another Viking experiment, the Gas Chromatograph/Mass Spectrometer (GCMS), failed to detect any organic molecules in the Martian soil. If there was no organic matter, it was argued, how could there be life?

Dr. Gilbert V. Levin, bioengineer and president of Biospherics Incorporated, was the designer of Viking's Labeled Release Experiment. Levin maintains that the results of the GCMS experiment do not necessarily rule out the presence of life on Mars. The Gas Chromatograph/Mass Spectrometer, he argues, was not sensitive enough to detect the small amount of organic matter necessary for life. In fact, a 1975 test of the GCMS failed to detect organic molecules in Antarctic test soil containing living microorganisms.

In the following interview, Dr. Levin recalls his experiences with the Viking program, and discusses why it is still too soon to rule out the possibility that Mars may be very much alive.

**Final Frontier:** *Three sophisticated and compact biology laboratories were packed onboard the Viking spacecraft into an area less than one cubic foot. Since all three experiments were designed to detect life, how well had they been thought out, given the hostile conditions on the surface of Mars?*

**Gilbert Levin:** Whether it was hindsight or foresight, NASA said that the three instruments selected were chosen based upon probable scenarios for life on Mars and the environment in which it lived. NASA officials published statements to the effect that if there was life on Mars, then probably only one of the three instruments sent there would detect it, because they each looked at such different possibilities for living systems.

The rationale for the Gas Exchange Experiment was to look for changes in atmospheric gases in an enclosed

space where a portion of Mars soil was first exposed merely to water vapor. This tested the "dry mode" concept of life on Mars. Next, a portion of the soil was exposed to a liquid nutrient containing many different sugars, amino acids, organic compounds and supplements. It was so complex we called it "chicken soup"—a name that has since stuck to it. With this "wet mode" test, it was hoped that the microorganisms would react to one or more of the components in the chicken soup and alter the composition of the atmosphere. The GEx experiment was conducted in the dark. It was not looking for photosynthetic microorganisms, which require light.

The Pyrolytic Release Experiment did look for photosynthetic microorganisms in the soil. It supplied radioactive carbon dioxide and carbon monoxide—both of which are present as gases in the Mars atmosphere—to a sample of soil exposed to a "sunlamp." If there were photosynthetic organisms present they would incorporate some of the radioactive gas. The excess or not-incorporated radioactive gas was then blown from the chamber. Next, the soil was heated to a high temperature to release any radioactive gas that had indeed been fixed by these organisms.

The Labeled Release Experiment used radio microbial metabolism technology, which I had invented years earlier...[It] revolves about providing radioactive compounds to media suspected of containing microorganisms and watching for radioactive gas to come off as evidence of their presence...Five compounds were selected for use in the LR experiment, two of which could be made as "left-handed" or "right-handed" molecules. Such molecules are chemically identical, but all life on Earth uses only right-handed carbohydrates and left-handed amino acids. Since we didn't know whether Mars life would prefer one form or the other, both left-handed and right-handed forms of those molecules were included. The LR experiment was carried out in the dark and was implemented by squirting a drop of the radioactive nutrient solution onto the center of a small sample. Water vapor immediately became available all over the surface of the soil. The center of the sample was wet and as the water moved out on the soil, the portions away from the center became moist and then wet. Thus, at some point, the microorganisms, if present, were subjected to humid, moist and dry modes. Since we were not looking for photosynthetic organisms in this experiment, the test chamber was in the dark.

The control, the same for all three

LEVIN PHOTO: MATTHEW BORKOSKI, 1983



Seasonal changes on Mars? Careful analysis of Viking images have revealed subtle color shifts on the Martian landscape. The one on the left was taken on Sol 28 (a Sol is one solar day on Mars), the one on the right was taken on Sol 615.

Viking life-detection experiments, was to heat a portion of any sample, producing a positive result to 160 degrees centigrade, let it cool, and then test it again. Organisms should have been killed, and a negative result would occur. A positive response would indicate a chemical in the soil.

**FF:** What types of simulations did you run to be sure your LR experiment would work on the surface of Mars?

**Levin:** Did we run simulations! We ran pure cultures of microorganisms, wild cultures, mixed cultures and we ran tests on soils that we obtained from all over the world. We took LR instruments out to Death Valley, California, and ran tests on the sand dunes and readily detected living organisms under the heat of the noontime summer sun under very dry conditions. We ran tests at the top of White Mountain, California, at about 12,000 feet and above the timberline, and found microorganisms thriving on the rocky surface. We got soil samples from Antarctica, the Gobi Desert and all kinds of places...As a final test, the LR instrument was put into a "Mars Box" at the NASA Ames Research Center, where it could be run under the same conditions it would experience on Mars. NASA scientists put a sample of California soil in the LR instrument, and let it sit for three days under Mars conditions before the test was done. The organisms withstood the Mars environment and produced a strong response.

Throughout our extensive test program over the years, the LR never produced any false positive or false negative results. The experiment proved to be extremely sensitive, having detected as few as ten colony-forming microbial units in a sample.

None of the other life-detecting instruments aboard Viking was nearly as sensitive, and the LR instrument was approximately one million more times sensitive than the GCMS. Thus, the minimum amount of organic matter, alive or dead, detectable by the GCMS needed to be one million times larger than the amount of living organic material detectable by the LR.

**FF:** Could you describe the events that took place when you first received the initial data from your LR experiment on the surface of Mars?

**Levin:** When we first saw the data from our experiment we were extremely excited and so was the group of people who were in the room that night. As a matter of fact, we rushed out and ordered a bottle of champagne and then all present signed that data strip attesting to the positive reaction, which

**"Why wasn't organic matter detected on Mars when all indications are strongly positive for it?"**

was thought to be history in the making. The data came in diagram form, several hours at a time, and when we first saw the radioactivity measurement on Mars take off, we didn't dare believe it would continue...probably just a fluke. But the next piece of data showed a strong continuous outpouring of gas and it seemed to follow the same pattern that microorganisms in soil produced in LR tests on Earth.

**FF:** How many times were you able to repeat the LR experiment?

**Levin:** All in all we ran nine LR experiments on Mars. We ran a test and control at each landing site and all were successful. On the basis of pre-mission criteria, the data showed the presence of life. However, after the GCMS failed to detect organics, many scientists suspected the LR results were due to active chemicals—peroxides—rather than life. Others said the results were induced by the ultraviolet light activating the Mars soil. So we modified some of the LR experiments to distinguish between living organisms and chemicals. One such experiment took a soil sample from under a rock in the pre-dawn hours on Mars. The rock had been in place for hundreds of thousands—even millions—of years so that no ultraviolet light had hit the sample. Also, it would have been difficult for hydrogen peroxide, thought to be formed by sunlight, to get under the rock. The sample from under the rock produced a strongly positive LR response and a negative control.

[Next] the ground control engineers were able to meet a request to send a signal to our LR instrument on Mars to raise the temperature to 50 degrees centigrade on a fresh portion of a sample previously shown to be "active." The sample was allowed to cool, and then the LR experiment was run. The result was a nearly 70 percent reduction in the response, firmly supporting the presence of living organisms over chemicals. Hydrogen peroxide decomposes about one percent each hour at 50 degrees centigrade, so heating it for three hours should not have caused the 70 percent reduction that we observed.

Finally, two Mars soil samples were

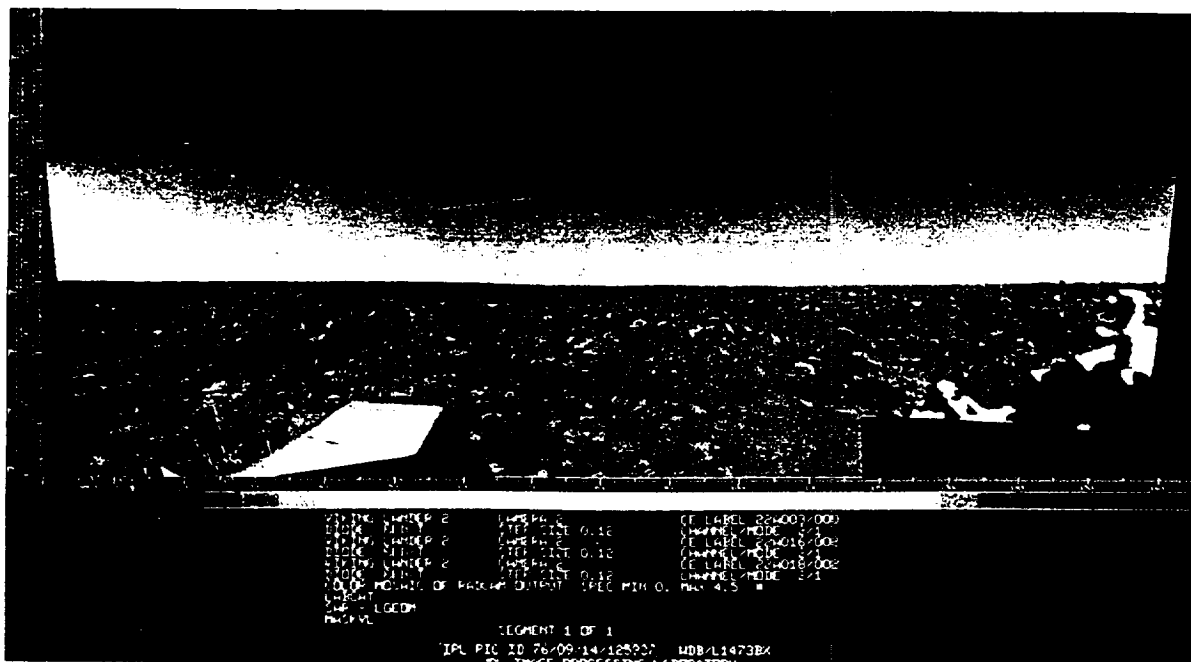
stored at seven to ten degrees centigrade in the soil hopper for two and three months respectively. Portions of both samples had been tested prior to storage and produced positive responses. After storage, each produced a "zilch" response. What was happening to the hydrogen peroxide or the chemical that was stored in the dark box? Was it somehow disappearing? If so, why was it there in the first place, since the surface of Mars approaches the temperature at which the samples were stored? Or is it more likely that microorganisms in the soil, sequestered from their environment and kept in the dark for a couple of months, had died?

**FF:** You spoke briefly about the non-biological experiment that was sent on Viking called the Gas Chromatograph/Mass Spectrometer or GCMS. This experiment was designed to detect organic molecules, the building blocks of life, and apparently the GCMS found no carbon-based compounds. Was the data from the GCMS in error?

**Levin:** I don't think the GCMS should have flown to Mars. Several years after Viking, I learned that, in the development of the GCMS, a number of tests were run on various soils supplied by NASA. I found in the GCMS archives that the instrument did not detect any organic matter in Antarctic soil sample #726. When simultaneously tested for organic matter by standard chemical analysis, 300 parts per million of organics were found in that soil. The GCMS was purported to be sensitive to several parts per billion. Well, it might have been sensitive to several parts per billion for chemicals in the "vapor phase," but apparently some organics are not vaporized by the abbreviated GCMS version sent to Mars. When I found that the GCMS had not been able to detect organics in this particular soil sample, I looked into the records of the LR experiment and found that we had been sent the same soil sample by NASA—Antarctic #726. Our records showed that the LR had clearly detected living organisms in it. So here we have an explanation that could accommodate both sets of results: The LR detected living organisms, but they were not numerous enough to provide the amount of organic matter required for detection by the GCMS.

There are good reasons to believe that organics do, indeed, exist on Mars. First, Mars is covered with craters from meteor impacts. Meteors carry organics and are important sources of organic input for the planets in our Solar System.

Secondly, thousands of tons of



organic matter contained in tiny interplanetary dust particles fall on Earth and also on Mars each year. Thirdly, small meteorites determined to have come to Earth from Mars contain organics. In addition, Dr. Norman Horowitz (designer of the Viking PR experiment) proved that organic matter must be made on Mars when the Sun shines through the Mars atmosphere. When he tested his PR experiment in a simulated Mars atmosphere on Earth, organic matter kept forming, giving him a false positive for life detection. Moreover, even though he kept his sunlamp on in his experiment, its ultraviolet light did not prevent the organic matter from accumulating. Horowitz published his findings before the Viking mission and said that it was likely that biologically significant amounts of organic matter had accumulated over the ages on Mars.

It might be worthwhile pointing out that the Moon samples brought back by the Apollo missions, when analyzed by a full GCMS, were shown to contain organic matter. It's hard to imagine that the Moon has organic matter, but Mars does not. The truth is that the instrument that tested the Moon material was far more sensitive than the miniature GCMS sent to Mars. The real question should be, "Why wasn't organic matter detected on Mars when all indications are strongly positive for it?"

**FF:** Later on in the Viking program you made some fascinating observations regarding the Mars rocks—namely, that some of them appeared to have greenish and other-colored areas that seemed to alter over time. Just how did you make this remarkable discovery

and what is its significance?

**Levin:** Stymied by not being able to get an answer that everyone could agree to on the LR results, I went back to JPL a couple of years later and spent some months. I guess in about two or three separate trips, looking at all ten thousand images that the two Viking landers took on Mars. I was hoping to find some kind of evidence that might help in the interpretation of the LR data. I found one thing very quickly—Mars is not uniformly orange-red in color as had been advertised after the first images were obtained...The colors ranged from ochre to yellowish, to olive, and even greenish.

In the course of looking at these images, I decided to compare images of the same rocks taken years apart. I was startled to find that the colored areas on some of the rocks seemed to have changed their patterns over a period of one Martian year, which is about two Earth years. Some colored areas seen on a rock shortly after the time of landing looked different one Mars year later. This was particularly true of some greenish spots.

I then got the color expert from the Viking imaging team and we performed a spectroanalysis of those images and the spots in question. We published this information along with pictures of these rocks. We also published the results of an experiment I performed by taking terrestrial rocks that had lichen growing on them and placing them in the JPL Mars lander area. This area had been structured to simulate the Viking I lander area and a Viking lander was placed in the center of it. I used the lander camera on the rocks under the simulated Mars light.

The results produced by the Viking camera and imaging system looked very much like the spots on the rocks in the actual Mars images. This doesn't prove anything and I never said it did, but I thought it would at least result in a more objective evaluation of the Mars LR data. However, what happened was that many scientists blatantly stated they did not believe the colors reported.

When I was at JPL, I showed these colored images to a NASA-supported scientist and he studied them. Subsequently, he published on the subject, confirming that there were indeed yellow, olive and even greenish spots on some of the rocks. He even found that the spots were elevated above the surface of the rock. Instead of discussing biology, he attributed these unusual findings to some type of weathering process on Mars. I think it would be an unusual sort of weathering that produces elevated spots of a different color than the rock. Normal weathering spalls or cracks the rock and the weathered material falls off. I am still working on these images and might have something further to report.

**FF:** If there is a possibility that Martian microorganisms exist, wouldn't it be irresponsible to send a crewed mission to Mars before making certain?

**Levin:** Yes, I think it would be irresponsible to send men and women to Mars if there is a possibility that there are living organisms there. This would expose humans to potential hazards, possibly bringing the hazard back to Earth upon their return. If we even bring samples of Mars back to Earth before we send humans, in opening those samples we

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could expose ourselves to the hazard. We should follow plans which have been made to deal with this possibility, but the plans are being largely ignored by the missions being readied by the U.S. and Russia.

**FF:** In 1674, Microscopist Anton van Leeuwenhoek claimed he saw strange "animalcules" (microorganisms), and it took science 200 years to prove finally that his observations were correct and not the exotic soil chemistry his colleagues claimed them to be. This sounds remarkably similar to the situation you appear to be in. How do you view this analogy?

**Levin:** I don't know if I'm in the same position as Leeuwenhoek or other scientists who made discoveries that were not readily accepted. I certainly hope it won't take 200 years for an objective evaluation of my data! Eventually, there will be trips to Mars that will determine the truth. But since NASA and the National Academy of Sciences said that the discovery of life on Mars would be one of the most important discoveries in the history of science, how can we wait? There should be a determined, objective evaluation of the Mars LR data by the science community. The truth is that life on Mars has become a political issue rather than a scientific issue. No objective scientist looking at the data can deny that the LR produced strong evidence for life on Mars. They may legitimately express caution; as I do, over an absolute conclusion, but to say as they do that there was no evidence for life on Mars flies in the face of the scientific method.

However, science is not a democratic process and I don't believe that Leeuwenhoek, Copernicus or Galileo ever had a majority opinion to support them...One of the problems with peer review is that it will never approve of any experiment or conclusion that is far away from the center of the knowledge of the peers. To do so would be for the peers to admit that they have been wrong or unobservant.

NASA officials and NASA-supported scientists may say that the "majority of scientists" believe Viking detected "no evidence for life," but after all these years to have avoided any symposium where those who had experiments on Viking could produce and discuss their data in the presence of peers and other scientists shows just how political the situation is. Yet, when people meet to discuss programs for future flights to Mars, they never allow for the possibility that there might be life on Mars and

they are preparing to bring samples back to Earth.

The natural path of science is that when you discover something through the use of some tool, you refine that tool and use it to elucidate further on that discovery. The next logical step, with respect to the LR experiment, would be to separate left- and right-handed isotopes and apply them individually to a Mars sample. I believe this would immediately settle the issue of life on Mars. If the left-handed and right-handed molecules of the same compound give different responses, unquestionably the source of the response is a biological one. If both types of molecules respond equally, the chemical theory gains the ascendancy.

Perhaps the most indefensible approach to the Mars life issue is that some "exobiologists" now say it is quite likely that life did originate on Mars when flowing water existed there, but that certainly life cannot exist under the present conditions. Therefore, instead of looking for living organisms they propose to look for the fossil remains of organisms...They flatly contend that, at some point, Mars organisms could no longer cope and became extinct. On Earth, there was a dramatic and rather sudden change in the environment of life, a change more severe than any known to have occurred on Mars. Life on Earth began as anaerobic organisms, which are poisoned by oxygen. Then photosynthetic organisms evolved and produced oxygen. Somehow, not only did the anaerobic organisms evolve to survive in this blanket of oxygen, they mutated to utilize the oxygen to their advantage and, voila, here we are today.

I think a scientific symposium should be convened to review all the Mars life data, to hear scientists express their varying conclusions, and to render a "verdict." I predict that verdict would find in favor of sending an advanced version of the LR experiment back to Mars as soon as possible to settle this major issue tantalizing humankind. I further predict that, more likely than not, we will find that we are not alone in the universe. ■

*Dr. Gilbert Levin is currently preparing an updated version of the LR experiment to fly aboard Russia's proposed Martian rover in 1996. He has also been named to the NASA Mars Soil Oxidant Team.*

*Barry E. DiGregorio's interview with Skylab Astronaut Ed Gibson appeared in our July/August 1992 issue.*



# A Colony in the Sky

After humans get to Mars, they'll start doing what comes naturally—turning it into another Earth. BY KIM STANLEY ROBINSON

ONE DAY EARLY IN THE NEXT CENTURY, SEVERAL PEOPLE will land on Mars. They will put on spacesuits and leave their vehicle, bounding over red rocks under a pink sky. After this exhilarating day, seen on Earth by billions, they will move into a cluster of habitats already on site. They will spend a year living there making scientific studies, and then they will return to Earth. Another team will cycle in. Back at home we will start to take the base for granted. Nevertheless, something very big will have begun.

The initial crossing to Mars will be made for a great number of reasons, some of them solid (to see if there really are fossil bacteria there), some of them not (to look for Elvis). Most of the reasons will be scientific and practical: the more we know about the solar system's other planets, the better we will understand Earth, and the safer we will be. It's not heroic but it makes sense, and it is important. Even if these were the only reasons, they would be good enough to send us.

But Mars will never remain just a research site to sharpen Earth management skills. We've been fascinated by the red wanderer ever since our days on the savannah, and even if life at the research station proves to be quite ordinary, the videos they send back will show us a magnificent world of volcanoes and canyons, icecaps and sand dunes, wind and weather. These wild new landscapes will also look somewhat familiar, especially in comparison to the bone-white moon. This familiar quality is not just superficial, for Mars does resemble Earth in several important ways—general size, presence of water, length of day, range of temperatures—so many similarities, in fact, that some people are beginning to ask if it might be possible to make Mars even more like Earth than it is now. And that's the question that will shift us to the next level of our fascination with the place: the idea that we could live there, that Mars could be "terraformed."

To terraform means to alter a planet's surface until Earth's life forms can survive there. It's a hypothetical discipline at this point, born in science-fiction stories. But in the last 30 years a number of scientists have taken up the concept. Their studies make it clear that the process would be somewhat slower than the cork-popping transformations seen in some recent sci-fi movies; in reality, it would take centuries. But it is an idea that operates within physical reality as we know it. It's possible to do it.

The recipe is simple. Add nitrogen and oxygen to the atmosphere; pump water to the surface; cook for decades, spicing first with cyanobacteria, then with all the rest of Earth's plants and animals, adding them in the order they evolved here. Mars is blessed with all the ingredients called for in the recipe; indeed,

Mars turns out to be perfect for terraforming. So, because we have all the life forms here at hand, we can try replaying evolution at extreme fast forward.

Of course it will be more complex than the recipe—it always is. And the process will certainly spiral out of our control. Eventually, however, if all goes well, we will have helped to start a new biosphere. Think of that! It's hard to know how even to characterize such an activity. It would be something like growing a garden, or creating a wilderness, or building a cathedral, or flying seeds over an ocean to drop them on a new island. It would be unlike anything else, a new thing in history.

Some people may believe that such a project is too large or slow or presumptuous for humanity to undertake. But consider our current situation on Earth. There are nearly 6 billion of us now, and the number may double, though we have no good idea how many of us the Earth can support. Many larger species are in danger of extinction unless we protect them from us. We have rearranged much of the land, and we have altered the atmosphere to the point where the global climate in the future will be a matter of legislation and industrial practice. In other words, we are already starting to terraform Earth by necessity to keep it livable. Given this situation, the attempt to terraform Mars does not look so outlandish. Doing it could be regarded as a valuable experiment, with Mars as a giant lab or university, in which we learn how to steward a planet's biosphere for long-term sustainability.

Long term indeed! Terraforming Mars would take 300 years at least. It's not a time scale we often think about, and it does seem unlikely that any society could persist in anything for so long. Luckily, the process will not depend on our consistent backing, but on the people who settle there and pursue it as their own closest interest.

As for us, here on Earth in the age of the quarterly statement, it is probably a good thing occasionally to contemplate a really long-term project. Humanity's existence on this Earth is a long-term project, after all, and it's important to remember what that means. People will be living here 500 years from now, and they will all be our relatives. These distant children of ours deserve to be given a livable planet to care for in their turn. For their sake we need to work out a sustainable way of life on Earth. Going to Mars will be part of that larger environmental project, and terraforming it will be an education that we will apply at home as we learn it—pausing, from time to time, to look up at our wilderness garden in the sky.

ROBINSON is the author of "Red Mars, Green Mars, Blue Mars," a prize-winning science-fiction trilogy about Mars.



Practice for space: NASA scientists build a mock colony

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# Martians Wanted: Dead or Alive!

by Christopher P. McKay

**H**istorically, Mars has been the focus of the search for life outside our own Earth. It was on Mars that astronomer Percival Lowell imagined a dying civilization building global water works and it was from Mars that the invaders of H.G. Wells came. Why Mars? Why not Jupiter, Venus or, even more close to home, the Moon?

The straightforward answer: Mars is the most Earth-like of the other planets. Even through a 19th century telescope, Mars can be seen to have polar caps that wax and wane with the seasons, and more suggestive, it has large dark areas that change through the Martian year in a manner reminiscent of vegetation to the predisposed observer. Viewed from Earth, Mars looked like we would have expected Earth to look like viewed from Mars.

But the illusion of a hospitable Mars was crushed forever in 1965 when Mariner 4 flew by that planet and relayed a set of pictures of a cratered lunar-like surface. The flybys of Mariner 6 and 7 confirmed the story: Mars was no Earth. But then Mariner 9, the first successful Mars orbiter, revealed a "new Mars," with towering volcanos, ancient river beds and flood channels—all dead. The prospects were still grim for extant life, but what a place it must have been in its day!

The Viking missions to Mars confirmed the verdict of *Star Trek*'s celluloid character, "Bones" McCoy—"It's dead, Jim." There was some activity in the Viking biology experiments, but the absence of organic material at the parts per billion level argued strongly against a biological explanation. Fur-



Chris McKay, "Antarctica astronaut," searches for clues to life on Mars question.

thermore, it appears that water does not exist in the liquid form anywhere on Mars at any time of the year—not a good sign since one essential requirement for all life on Earth (to grow and reproduce) is liquid water. But Viking also confirmed the evidence that Mars had been a "kinder, gentler" place, albeit many years ago.

"Many years ago" was probably about 3.8 billion years. That seems to be the age of the ancient river networks. The presence of these den-

driftic drainage features indicates that liquid water was fairly stable on the surface of Mars for extended periods of time. Where there is liquid water, there is the possibility of life. Hence, it is that period 3.8 billion years ago on Mars that is of most interest biologically. This was the time when Mars was indeed like the Earth.

On Earth, the period from about 4 billion years ago to 3.5 billion years ago was the critical period for life—these were the "formative years" for



Airtwork: Robert Murray/Martin Marietta Astronautics

Mars expedition member collects samples from an arroyo.

planet/life interactions. We have direct evidence for life on Earth at 3.5 billion years and suggestive evidence for life at 3.8 billion years ago. Life could actually have originated much earlier but the fossil record of that early period has been destroyed—by the very tectonic activity and biogeochemical cycles that keeps the planet alive. Our studies of Mars' early climate and studies of Earth's earliest biosphere suggest that liquid water habitats persisted on Mars for as long as it took life to evolve on Earth. Perhaps then, life also evolved on Mars.

The task before us then is to search for fossil evidence of life on Mars 3.5 to 4 billion years of age. The obvious places to look for fossil remnants of early life are the locations where there were standing bodies of water on Mars 3.8 billion years ago—dry lake beds. Lakes are good places for life to flourish, but more importantly, when an organism dies in a lake its remains have a good chance of being preserved in the sediments on the lake bottom. There are several sites on Mars that have been identified, based upon photogeological data, as lake beds dating back to 3.8 billion years ago.

Three and a half billion years ago, life on Earth was microscopic. In fact, larger multicellular organisms didn't originate until billions of years later. Thus we would expect that the life-forms on early Mars were also microscopic. It is hard to find microscopic fossils. However, one of the most important forms of fossils on Earth are stromatolites. These are large structures, often many meters in size, built by the successive phototactic (toward

light) movement of layers of microorganisms through sediment. On Earth, stromatolites are a key to determining the date of the earliest life. Given a similar phototactic response of Martian life, stromatolites may have also been built there. Searching the shoreline of an ancient Martian lake for stromatolites may be possible with an automated rover mission to Mars.

If Mars did have liquid water, and life, what happened to it? Clearly, there have been some drastic changes in the climate of that planet. Current theories of planetary evolution suggest that the fundamental problem with Mars was not its increased distance from the Sun (compared to the Earth) but its lack of plate tectonics. In the presence of liquid water, atmospheric carbon dioxide is depleted due to the formation of carbonate. On the early Earth, subduction of carbonate-containing sedimentary material at plate boundaries provided a mechanism of recycling carbon dioxide back into the atmosphere, maintaining the essential greenhouse effect. On Mars, without plate tectonics to recycle the carbonate, the atmosphere would rapidly be depleted and the planet would have become too cold to sustain life. Estimates based upon the Antarctic dry valley lakes

suggest that life could have persisted for about 700 million years after the mean temperatures fell below freezing. After that, it would have been "all she wrote" for life on Mars.

But maybe not. Everything needed to make Mars a habitable planet may still be there: carbon tied up as carbonate, water frozen into the soil, and nitrogen tied up as nitrate. If so, it may be possible someday to restore the atmosphere and bring back life to the Red Planet. There may still be another chapter to write on the story of life on Mars. Our studies of the early climate of Mars will provide the blueprint for the future revitalization of that planet.

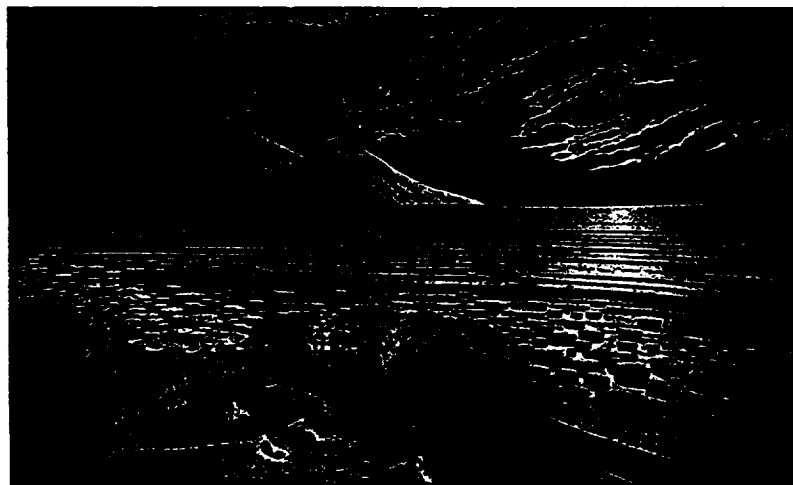
Searching for fossil evidence of early life on Mars will surely be a key science objective for human exploration of that planet. Martian paleontology is inarguably one of the science areas in which the presence of humans is required to do the job. Biologists will not just search Mars for fossils. They will also determine if life there really is extinct, or if it has survived in some special localized niche.

Because of the paucity of the fossil record on Earth, and the fact that over two thirds of the Martian surface dates back to 3.8 billion years ago—having spent the time preserved in deep freeze—it may well be that we must go to Mars to really learn the origin of life on our own planet and begin to answer THE question: are we alone? ☆

*Christopher McKay is a research scientist in the space science division of NASA's Ames Research Center. He specializes in the life on Mars question, frequently visiting Antarctica as part of his studies.*

*The thick clumps in the foreground are stromatolites produced by algae, one of the earliest forms of life on Earth.*

*Early life on Mars may have developed similar structures in the planet's channels or lakes.*



Airtwork: Peter Sawyer Photo: Chip Clark/Smithsonian Institution

# CAN A DEAD WORLD BE BROUGHT TO LIFE? THE GREENING OF G OF THE RED PLANET MAY BE THE NEXT GIANT STEP FOR MANKIND

**T**he Roman god of war was a grisly brute, and the planet that bears his name is no less hideous. Its crust, the color of dried blood, is ulcerated by meteorites, studded with volcanoes (one of them the size of Montana), slashed by gorges that make the Grand Canyon look like a creek bed. Over this scene streams an atmosphere so cold it turns carbon dioxide into dry ice and so thin a human being who ventured into it without a space suit would die in minutes.

Mars, as a lengthy series of unmanned missions has made clear, fully deserves its ugly reputation. Ancient astrologers deplored "the bloody planet" as a baleful influence. Nineteenth-century astronomers, who thought they saw canals on its surface, imagined mysterious canal builders, and writers of science fiction eagerly depicted them as little green men, as weird humanoids, as giant octopi with genius IQs. When the Viking landers sent back photos of its dreary surface, Mars lost some of its glamour. But now scientific interest has revived, and the red planet has recaptured popular imagination. Mars is the subject of "Genesis," an epic poem by Frederick Turner; of *Mars Beckons*, a book by Pulitzer Prize winner John Noble Wilford; of front-page articles in major newspapers. Mars supplied the setting for a recent Hollywood blockbuster (*Total Recall*) and will be the centerpiece of a new exhibit depicting the future of space exploration at the Smithsonian's National Air and Space Museum.

And with presidential blessing, Mars has become the darling of the U.S. space program. Prompted by the need to refocus a floundering NASA, George Bush has announced a "New Age of Exploration" in which American astronauts will construct a space station in Earth orbit, establish a permanent base on the Moon, and then, before the year 2020, land human beings on Earth's planetary neighbor. Project Mars, say administration spokesmen, will power a revolution in science and technology, boost the economy, reanimate the educational system and elevate national morale. On White House orders, blue-ribbon panels of

aerospace experts have been developing a strategic plan to achieve the President's goal: "The American flag should be planted on Mars."

Many Americans are appalled. Why, they ask, should U.S. taxpayers, faced with home-planet problems like poverty, homelessness and pollution, spend billions and risk lives to rummage on a rock pile somewhere in outer space? But to a rising generation of space scientists, the self-proclaimed "Mars Underground," NASA's new initiatives seem timid. "It's ridiculous to go all the way to Mars just to plant the flag, grab a few rocks and come home," says biophysicist Robert Haynes. "Humanity needs a new vision, a new challenge, not a cosmic park. Mars could provide that challenge."

Humanity's challenge, as NASA's Young Turks see it, is to re-create Creation—to play God. They propose that the United States, the Soviet Union, Europe and Japan attempt the most ambitious engineering project in human history: the "terraformation" of Mars, the greening of the red planet. They want to transform Mars into a new home for humankind—and they believe they can do it in less than two centuries.

Is terraformation just fantascience, the reverie of spaced-out brains? With surprisingly few exceptions, major scientists believe we should investigate the possibility of terraformation, though many doubt that Mars could be renovated for a price this planet can afford. The investment will be large, but the return could be prodigious. And if we don't terraform Mars, some scientists warn, we may be sorry. Noting that nuclear holocaust, runaway pollution or the impact of a giant meteorite could terminate human civilization, John Rummel, chief of research for NASA's life sciences branch, concludes: "I think it is foolish to put all our eggs in one basket. It would be wise to look for a place other than Earth where this species could make a home. It would be wise to learn how to terraform Mars."

It would also be smart to look before we leap.

## MARS

# THE PLANET THAT ONCE WAS WARM

**I**magine for a moment that you're sipping a cup of coffee and reading this issue of *LIFE* magazine, but the cover story is not about terraforming Mars, it's about terraforming a nearby planet called Earth. The article speculates about what went wrong on Earth, why the atmosphere there is so thin yet the air on Mars is ample, why all the water on Earth disappeared yet Mars is half-covered with lakes and seas, why Earth cooled too much yet Mars cooled until it was just right. All this is puzzling, the article says, because in the first billion years of their existence the two worlds were so much alike—planetary twins.

The scenario is not absurd. Earth and Mars were indeed so similar at one time that Mars, not Earth, might well have become the paradise. Born about 4.6 billion years ago out of the same cloud of interstellar dust and debris, both Mars and Earth were initially hostile to life. Superheated and covered with huge volcanoes spewing steam, lava and toxic fumes, they were also under constant bombardment by meteorites left over from the formation of the solar system. Volcanic emissions and collisions with comets produced thick atmospheres of carbon dioxide, nitrogen and water vapor. Steam collected in dense clouds that shut out the Sun and poured rain down on the hot crusts of the young planets for 100 million years.

On Mars, immense features were gouged out by rivers a thousand times larger than the Mississippi. Streams, lakes and oceans formed. The presence of ancient riverbeds, now dry, suggests that water must have existed on the surface for long periods of time. Through this warm primordial soup coursed all the elements required to create amino acids, the building blocks of life. For hundreds of millions of years, both planets may have been temperate, moist environments with everything necessary to support the formation of life. The scene was set.

On Earth, life appeared about 3.8 billion years ago in the form of microorganisms. On Mars, similar microbes may have developed at about the same time. Then, several hundred million years later, as single-celled animals on Earth began their long struggle to evolve, something went wrong on Mars. Some scientists theorize that because Mars is only half the size of Earth it could not muster enough gravity to hold onto its atmosphere, which steadily escaped into space. Others believe that the carbon dioxide atmosphere grew thinner because it slowly but surely combined with surface minerals to form carbonate rocks. In either case, as Mars lost its gaseous cloak, the planet's ability to retain the Sun's heat lessened. And because the thinner atmosphere was unable to prevent the Sun's deadly ultraviolet radiation from reaching the surface, Mars changed from a wet, warm nursery to a dry, freezing desert.

Under such conditions, no life as we know it could survive, but many scientists believe that fossil evidence of early life can still be found on Mars. Some even suspect that tenacious microbes may be living deep inside still-warm volcanoes or in aquifers below the permafrost. Simple organisms, they note, have been found thousands of feet below the surface of the earth and on the bottom of Antarctica's perpetually frozen lakes.

Whether or not life exists or has ever existed on Mars is a subject that raises questions. If living things never existed there, perhaps life's magic moment happened only on Earth. That sense of uniqueness could encourage us to be more caring of our own planet.

If living things or even fossils are discovered on Mars, perhaps life is relatively commonplace, found wherever in the universe water, carbon and a few other elements mingle. In that case, what was once a planet that may have held the hot breath of life is a planet that could hold it again.

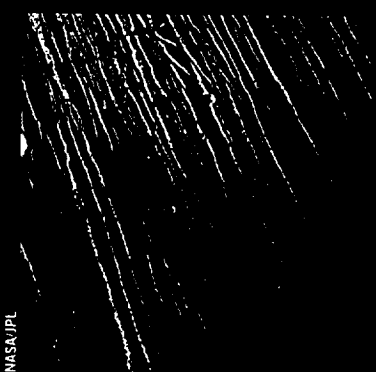
One of many indications that water once flowed on Mars is this photo mosaic (above) taken in 1976 by a Viking orbiter. Like a riverbed on Earth, the 360-mile-long system is fed by branches, suggesting drainage of a valley area. More than 100 Viking photos were put together to form an image (opposite) of nearly half of Mars. Although there is no "right side up" in space, the collage is seen rotated, with the equator running from top to bottom on the page. The gash in the planet's midriff is the Valles Marineris, a 2,800-mile-long canyon.

NASA/JPL

ALFRED MCWEN/UNITED STATES GEOLOGICAL SURVEY

TEXT: BILL STEVE P  
REPORT: ANNE H

# A LAND OF STAGGERING PROPORTIONS



The volcano Olympus Mons (top), 360 miles across and 16 miles high, was photographed during early martian summer, surrounded by clouds of water ice. Mars's vast plains are often fractured (above) by parallel troughs and ridges. The longer fault lines in the photo run for 110 miles. Opposite: Landslides are believed to have caused the clifflike features in the Ophir Chasm, part of the Valles Marineris canyon system near the martian equator. Each of the cliffs is about 15 miles wide and more than 12,000 feet high. The two Viking spacecraft that took these photos arrived at Mars in June and August of 1976. Each then sent a lander to the surface. Next to the Hubble telescope, the Vikings are considered the most sophisticated spacecraft ever built.

Oh, what a fascinating walk you could take near the martian equator next December, in the middle of a summer day. The weather would be perfect—high 60s and a bright orange Creamsicle-colored sky—but shirtsleeves would be out. You'd be wearing a light space suit to keep your blood from boiling because the "air" on Mars is so thin, about the same density as Earth's at 20 miles above sea level. The space suit would help with two other problems—the deadly ultraviolet light from the Sun, and the unbreathable martian atmosphere, which is 95 percent carbon dioxide, with traces of nitrogen and argon.

The physical act of walking would seem effortless; you could endlessly hop, skip or jump along because gravity is only about a third of what it is on Earth. A 100-pound woman would feel as if she weighed 38 pounds, and a world-class athlete could run 100 meters in less than five seconds. The vista would remind you of the Arizona and California deserts—fine sand littered with rocks and boulders. But the sand would be pink and reddish-brown, because martian soil is about 13 percent iron, much of which has turned to rust. Of course, there wouldn't be any cacti or scrub plants like tumbleweed, any darting lizards or rabbits. The terrain would be much drier than any desert on Earth, so dry that an ice cube placed on the ground would quickly disappear, evaporating before it could melt, going straight from solid to vapor.

You could walk just about anywhere you wanted on Mars, because the entire surface is land; there are no lakes, rivers or oceans. All the water is underground or frozen at the north and south poles. There's as much land on Mars as there is on Earth, even though Mars is only half as big as Earth and weighs only a tenth as much. Because of its weaker gravity, Mars is not as dense as Earth; it's puffed up. A thousand feet below the surface of Earth you would probably hit solid rock, but a thousand feet below the crust of Mars you would find porous material, perhaps even a gravelly slurry of rock and ice.

A day's walk on Mars would offer about as much Sun time as on Earth; Mars rotates once every 24 hours, 37 minutes. But the summer would last twice as long because Mars takes 687 days to orbit the Sun.

A trek to any of Earth's natural wonders would pale by comparison to what can be seen on Mars. Mount Everest, at just over 29,000 feet, would seem a foothill compared to the Tharsis bulge, a broad raised equatorial plain the size of the United States. On Tharsis sit extraordinary volcanoes, among them Olympus Mons, at 90,000 feet the highest known elevation in the solar system. The mighty Colorado River's cut through the Grand Canyon would seem a drainage ditch next to Valles Marineris, a gorge that would stretch from Seattle to Miami.

Martian volcanoes are so majestic because the planet's crust moves very little. When a surface forms over what geologists call a hot spot, lava flows up, a volcano begins to build, and it may never stop. On Earth, volcanoes form the same way. But eventually, because Earth's crust keeps moving, the volcano moves with it, and the hot spot is covered up. No one knows how Valles Marineris was formed, but geologists speculate that the planet's crust split open, leaving a four-mile-deep trough into which water and lava flowed. A similar but smaller rift may have formed the trough that is filled by our Red Sea.

You could spend a lifetime on the surface of Mars and never run out of new formations to see. The southern hemisphere, dimpled by moon-like meteorite craters, is completely different from the northern hemisphere, which is smoother but more volcanic. Just one thing, though. You would want to get back to base before dark. Most nights, even in summer, the temperature drops to about  $-125^{\circ}\text{F}$ .



## REMAKING MARS INTO EARTH2

**T**he human brain has a formidable record of accomplishment. But it may never have confronted a challenge as awesome as the terraformation of Mars. We will have to raise the entire planet's temperature by 100° F, transmute its girdle of lethal gas into an atmosphere humans can breathe, erect a global shield against solar radiation, build heavy industries on martian soil, construct farms and cities in biospheric bubbles, and transport thousands of people, plants and animals to Mars in a fleet of interplanetary arks. Even the most eager partisans are abashed by the size of the undertaking, but there is rough agreement on how it might be accomplished. The views of dozens of leading space scientists are reflected in this six-stage scenario.

**1** The first earthlings will arrive on Mars during this phase (2015-2030), which will begin almost exactly four centuries after the Pilgrims landed near Plymouth Rock. After a three-month flight from Earth, their *Mangflower*, a nuclear-powered rocket not yet built, will deposit them on the martian surface in a prefabricated colony designed to shelter 12 to 14 astronauts for a year.

The Mars team will be too busy to get homesick. They will grow experimental crops, analyze the atmosphere, dust storms and solar radiation, drill geological cores, explore the surface for 500 miles around, search for signs of life past and present, and monitor their own emotional and physical responses. Outside the biosphere, they will wear pressurized space suits and converse by radio; the martian atmosphere is too thin to carry the sound of a human voice.

If Europe, Japan and the U.S.S.R. cooperate, more than one team may be working on Mars at the same time. By 2030, we should know if Mars can be terraformed.

The cost of this phase is estimated at several hundred billion dollars—about half the amount Americans will spend for pizza in the same period.

**2** Now comes the hard part. The first step in the process of terraformation, which will begin in this phase (2030-2080), is to warm the planet, and the trick is getting started. Raising the mean temperature of Mars from -76° F to -40° F, the job assigned to this phase, will be roughly as difficult as melting Antarctica. Many

ways of warming the planet have been suggested; this is the most plausible combination of steps:

1. Build chemical factories on Mars, power them with small nuclear reactors imported from Earth, and pump out greenhouse gases like carbon tetrafluoride or sulfur hexafluoride that will cover the planet with a thick blanket and prevent the escape of heat. The components of all these chemicals are present in the martian crust.

2. To prevent reflection of heat into space, darken the gleaming polar ice caps by spraying them with a fine black powder or by scattering genetically engineered microorganisms that will multiply on the polar ice, covering it with a dull film.

3. Suspend an array of Mylar mirrors, each many square miles in area, in orbit over the martian poles to melt the ice caps by reflecting sunlight on them.

As the atmosphere thickens, the temperature will rise, and as the temperature rises, the atmosphere will become still thicker—a beneficent cycle that will leach more and more carbon dioxide, nitrogen and water vapor out of the porous rocks. But the martian air may never get thick enough to shelter the surface from the Sun's deadly ultraviolet rays. On Earth, ozone does the job; but ozone is a form of oxygen, and on Mars there will be hardly any oxygen during Phase 2. An ozone substitute will have to be developed, manufactured on Mars and pumped into the atmosphere to create a planetary parasol. If the new gas, like ozone, forms a fairly stable layer high in the atmosphere, a little should go a long way. Earth's ozone layer averages between three and five miles in depth, but if all that ozone were brought down to the surface, it would form a layer only one tenth of an inch thick.

In the early stages of terraforming, most of the settlers will be scientists, engineers, agronomists, physicians, skilled mechanics—perhaps 10,000 in all. Their life there will be rugged. Except for an occasional stroll in a pressurized space suit, they will work, play, eat, sleep and huddle together in biospheres—aliens in air bubbles.

The cost of this phase is estimated at \$15 billion a year—big money, but only half again as much as we may spend to clean up the S&L mess.

**3** The worst is over. In this stage (2080-2115) the planet will start to work with us instead of against us. As it warms from a mean temperature of -40° F to 5° F, carbon dioxide, nitrogen and water will seep from the crust in ever increasing amounts, and the atmosphere will continue to thicken. Puffy white clouds will pile up, and the sky will slowly shift from pink to pale blue to royal blue. Air pressure will rise gradually to about half the pressure at Earth's surface—about what it is at 18,000 feet. Water will pool in deep canyons. Meanwhile, as soon as the mean temperature reaches -15° F, tundra vegetation will be able to survive in warmer latitudes.

Thanks to immigration and a rising birthrate, population will swell slowly to about 50,000. Biospheres will multiply. Dirt roads will be bulldozed. Midway in this period, people will trade space suits for rebreathers (air-tight face masks attached to small oxygen tanks and designed to reuse gases expelled by the lungs). These devices will contain voice amplifiers instead of two-way radios. The atmosphere will now be thick enough to carry

3

# THE BIG THAW

TIME FRAME: 2080-2115.

W: Continue warming, alter atmosphere.

TECHNOLOGY: Oxygen factories added. Re-breathers replace space suits.

CHANGE: Average temperature rises to 5° F. Oxygen builds up in atmosphere. Clouds increase, sky turns blue. Tundra plants introduced.

2

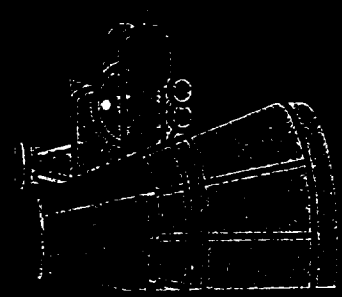
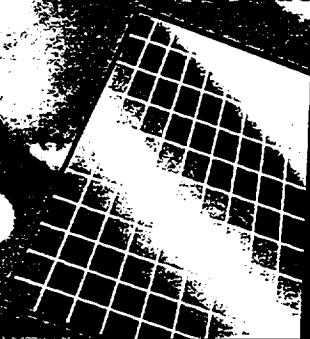
# THE WARMING

TIME FRAME: 2080-2115.

W: Continue warming, alter atmosphere.

TECHNOLOGY: Oxygen factories added. Re-breathers replace space suits.

CHANGE: Average temperature rises from -76° F to -40° F. Carbon dioxide, nitrogen and water vapor released from chest-ice.



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FROM : G420-M  
FRANK PALLUCONI - JPL

# BASIC MARS INFORMATION

Frank Palluconi

1. Distance from sun: Mars minimum 207 million km  
maximum 249 million km

Earth average 150 million km

The amount of energy from the sun falling on a given area changes with distance as one divided by the distance squared. As a result when Mars is furthest from the sun only 36% as much sunlight falls on a given areas as for earth.

2. The rotation axis of Mars is inclined 24 1/2° from the orbit plane, nearly the same as the earth.

3. Mars rotates a little more slowly than the earth taking 24 hours and 39 minutes on average to rotate with respect to the sun.

4. Because the Mars orbit is more eccentric than the orbit of the earth the seasons are not of equal length. The table below gives the length of each season in Mars days and earth days.

SEASON		LENGTH OF SEASON	
NO. HEMISPHERE	SO. HEMISPHERE	MARS DAYS	EARTH DAYS
Spring	Autumn	194	199
Summer	Winter	178	183
Autumn	Spring	143	147
<u>Winter</u>	<u>Summer</u>	<u>154</u>	<u>158</u>
TOTAL		669	687

5. The atmosphere of Mars is much less dense than the atmosphere of the earth. The surface pressure is only 6 millibars compared to 1013 millibars for the earth. In addition some of the atmosphere condenses on the surface as snow in the winter hemisphere so the pressure changes by  $\pm 20\%$  during the year.

6. The atmosphere of Mars is almost all carbon dioxide (95.3%) with 2.7% Nitrogen, 1.6% Argon and 0.13% of Oxygen. The earth's atmosphere has 21% oxygen. There are also small amounts (less than 0.1%) of carbon monoxide, water vapor, neon, krypton, xenon, and ozone.

7. Although there is only a small and variable (less than .03%) amount of water in the Mars atmosphere the temperature of the atmosphere is low so the relative humidity can often be high (near 100%) and water clouds as well as carbon dioxide clouds do

form in the atmosphere. The permanent polar cap covering the North pole is known to be composed of water ice. The permanent cap in the south may contain water but it could be all carbon dioxide. Because of the low surface pressure at the surface of Mars, liquid water cannot exist at the surface. If you introduce liquid water it will freeze and sublime into the atmosphere. Most of the water on Mars is likely frozen beneath the surface. Chances of finding this frozen water get better the higher the latitude.

8. The composition of the Martian surface is not well known, but there are ample amounts of silicon, aluminum, iron, magnesium, and calcium. There is also some titanium, sulfur and chlorine. For use in construction it would be useful if sand and gravel were present. There are large dunes on Mars but their composition is not known. No gravel is known to exist, but only a small area of the surface has been seen at high resolution.

9. There are many types of terrain on Mars including volcanoes, plains, river valleys, canyons, craters, and dust deposits. In the areas seen at high resolution there are abundant rocks.

10. When Mars approaches its closest to the sun in Southern spring, strong winds lift dust from the surface and sometimes a global dust storm occurs. When such a storm occurs it can be dusty for months greatly reducing the amount of sunlight reaching the surface.

11. Because the atmosphere is thin, the daily range of surface temperatures is very large ( $100^{\circ}\text{C}$ ) so the temperature even near the equator can go from room temperature ( $20^{\circ}\text{C}$ ) to  $-80^{\circ}\text{C}$  in less than twelve hours. In the winter hemisphere where the sun does not rise all day, the temperature can fall to  $-123^{\circ}\text{C}$  and carbon dioxide snows out of the atmosphere. The average surface temperature is about  $-50^{\circ}\text{C}$ .

12. Mars is a smaller planet than the earth. Its equatorial radius is 3394 km and the polar radius 3375km. The surface gravity is only 38% ( $371\text{cm. Sec}^{-2}$ ) that of earth due to the smaller mass of Mars compared to earth.

# Breakthroughs

IN SCIENCE, TECHNOLOGY, AND MEDICINE

## SPACE

### A Coolness on Mars

**M**UCH OF WHAT WE KNOW ABOUT Mars' climate is shaped by reports from the two *Viking* missions of the mid-1970s. But evidence collected over just a few years can give a misleading impression of a planet's long-term climate. Recently the Hubble Space Telescope helped confirm what some astronomers suspected: the relatively warm planet seen by the *Viking* probes was in only one phase of a complex weather cycle.

The Hubble found wispy Martian clouds, a sign that water is freezing out of Mars' air. This fits nicely with seven years' worth of radio astronomy work by Todd Clancy at the Space Science Institute in Boulder, Colorado. By looking at global temperatures and atmospheric water content, Clancy has found that Mars has two profoundly distinct seasons: a warm, dusty southern summer and a cold, dust-free northern one.

Like Earth's, Mars' axis of rotation

is tilted with respect to the sun, so when it's summer in Mars' southern hemisphere, it's winter in the north. But unlike Earth, which receives about the same amount of sunlight year-round, Mars, because of its more elliptical orbit, gets radically different doses of solar energy in different seasons. During the southern summer, Mars is 36 million miles closer to the sun than it is during the northern summer. The planet receives more solar energy during the southern summer and it also retains more: the extra sunlight drives storms that often blanket the planet with dust. The dust absorbs sunlight, further warming the atmosphere.

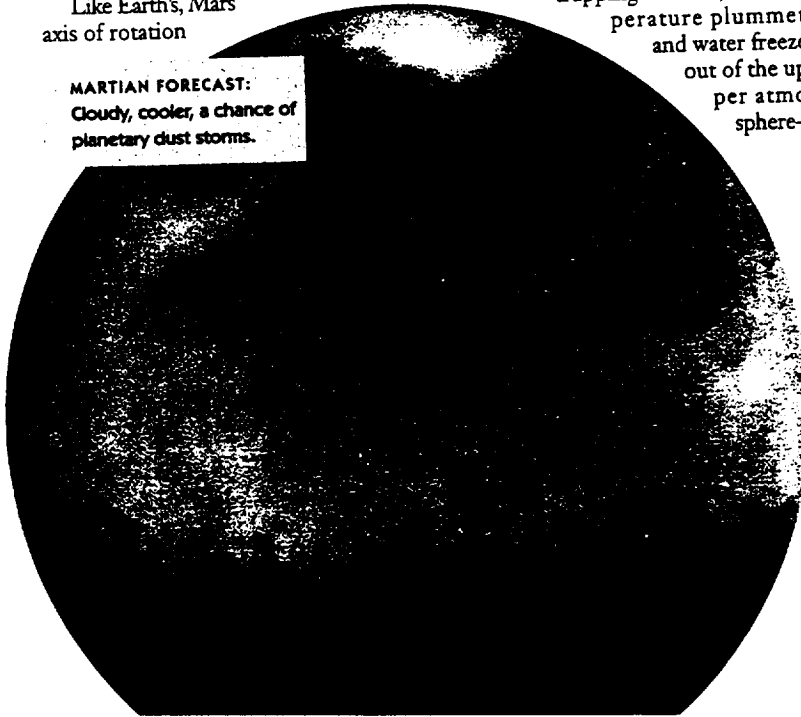
That has a big effect on Mars' water cycle. The atmosphere can become so warm during the southern summer that water vapor rises into the upper atmosphere without condensing into ice crystals. High-altitude winds then spread the vapor around the planet. During the cooler northern summer that follows, however, the storms abate and the dust settles. Without a heat-trapping blanket, the temperature plummets and water freezes out of the upper atmosphere—

forming the clouds that the Hubble saw.

This water cycle, says Clancy, may be the solution to a long-standing puzzle about Mars: Why is the permanent ice cap on the south pole smaller than the northern one? The reason may be that the northern ice cap steals water from the southern hemisphere. During southern summers, when frost in the soil or ice at the pole vaporizes, a little bit of the vapor reaches the upper atmosphere and gets carried to the northern hemisphere—where it freezes out of the atmosphere. Because the northern summer is cooler, says Clancy, the water never makes the return trip: water coming off the northern ice cap condenses in the lower atmosphere and never reaches higher altitudes where winds might carry it south.

The *Viking* probes never saw a typically cool northern summer. They landed during a freak period when two straight years of intense southern dust storms—which normally happen only every other year or so—had left a pall that made the northern summer unusually warm. "Every time I've measured the temperatures in that season, it's been 20 to 30 degrees colder than what *Viking* measured," says Clancy. And because the dust created the salmon pink skies in the *Viking* photographs, an observer on Mars would now see a startling difference. Says University of Toledo astronomer Philip James, who worked on the Hubble images, "It would be a dark blue, almost violet in color—something like what you'd see on top of a high mountain."

**MARTIAN FORECAST:**  
Cloudy, cooler, a chance of  
planetary dust storms.





## Mars: Just the Facts

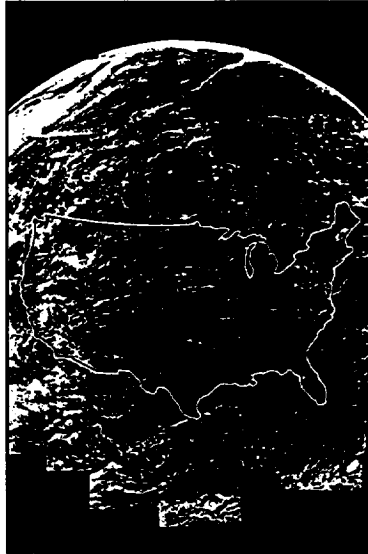
by Dr. Mark Chartrand

Ares to the Greeks, Mars to the Romans—the planet voted most likely imagined to sustain life. Although none has been found thus far, three decades from now humans may establish permanent settlements on the Red Planet.

The average distance of Mars from the Sun is 141.6 million miles (227.9 million km), 1.524 times the size of Earth's orbit. Mars, however, has the third most elliptical orbit of the planets, which means that it can get as close to the Sun as 128.4 million miles (206.7 million km) and as far away as 154.7 million miles (249.1 million km). At its mean distance, Mars receives only 43 percent of the Sun's energy we get on Earth. At this average distance, Mars takes 686.98 Earth days, or 1.88 Earth years, to complete one orbit.

Mars has an equatorial diameter of 4,218 miles (6,787 km), about 53 percent that of Earth, making it the third-smallest planet in the Solar System. The planet is tilted over, compared to a line perpendicular to its orbital plane, by 25.2 degrees. (For comparison, Earth is tilted 23.4 degrees.) This produces seasons on Mars, but correspondingly longer than those on Earth. On Mars, spring in the northern hemisphere lasts 198 days, summer is 184 days long, autumn is 147 days long and winter lasts 158 days.

Mars rotates on its axis in 1.0260 Earth days, about 24 hours, 37 minutes Earth time. The northern end of the rotational axis of the planet does not point to the same place in the sky as does Earth's axis (which we call the North Star, Polaris). There is no bright star close to Mars' north pole. The nearest is Deneb, in the constellation Cygnus, about 10 degrees away; a fainter star, Mu Cephei, is a bit closer.



With a mass only 11 percent that of the Earth's, given Mars' size, the gravity on the surface is only about 38 percent that of Earth making Mars unable to hold on to as thick an atmosphere.

The atmospheric pressure on the surface of Mars is .007 atmospheres, too little to allow humans to go outside unprotected, even if they could breathe the air. The major ingredients of the Martian atmosphere are: carbon dioxide, 95 percent; nitrogen, 2.7 percent; argon, 1.6 percent. Oxygen is only about a 0.1 percent of the Martian air.

Because of the thin atmosphere and distance from the Sun, it never gets very warm on Mars. Average temperatures are around 60 Fahrenheit degrees below the freezing point of water; at noon on the equator it may get up to freezing. The thin atmosphere means that there is little greenhouse effect warming, and that the night cools off quickly to far below

zero. Mars' atmosphere shows all of the large-scale movement phenomena seen on Earth, and one unique to Mars: "condensation flow" caused by the dry-ice polar caps alternately condensing and subliming. Winds reach several hundred miles an hour, but lack the power of Earth storms because the air is so thin.

Mars' two small satellites move through the Martian sky in usual ways. Phobos, the inner satellite, is only 13 miles (21 km) across and is shaped like a lumpy potato. Orbiting 5,800 miles (9,400 km) from Mars' center, and thus only 1,600 miles (2,600 km) above the surface of Mars, it takes less than one-third of a Martian day to orbit once. Seen from the surface of Mars, Phobos would rise in the west and set in the east, usually a couple times a day! Even so, it lacks brightness because of its small size, the reduced sunlight and Phobos' very dark surface.

Deimos, 7.5 miles (12 km) in size, is 14,600 miles (23,500 km) from Mars' center and takes 1.3 Martian days to orbit once. Seen from Mars, Deimos would rise, hang in the sky for days before setting, and then set for several days. It, too, would be hard to see by Mars settlers.

The brightest object by far in the evening and dawn skies of Mars would be Earth, never seen more than about 41 degrees from the Sun (similar to how Venus is viewed from Earth). Venus viewed from Mars is always seen within 35 degrees of the Sun, and Mercury would be hard to spot, never more than 15 degrees from the Sun.

Many of these facts will serve as crucial "basics" needed to transform Mars into humankind's second planetary niche in the Solar System. ☆

